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Technical research into construction standards for e-scooters

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Executive Summary

This project was conducted by TRL and Warwick Manufacturing Group (WMG), University of Warwick, on behalf of the Department for Transport (DfT). The aim of the project was to provide guidance to the DfT on certain aspects of technical regulations that may in future be applied to e-scooters if their use in public places is to be made legal. This report documents the range of activities that were conducted to collect evidence around certain aspects of the safety, sustainability and accessibility of e-scooters and the recommendations arising from that evidence.

A range of methods were employed, including a review of regulations and standards for e-scooters, EAPCs and ‘invalid carriages’ in both the UK and Europe, engagement with a wide range of stakeholders drawn from the e-scooter industry, disability charities, safety organisations and the police, physical testing and experimentation, and theoretical analysis.

The project was separated into four main work packages:

Work Package 1 Review of literature and international regulations and standards

Work Package 2 Analysis of technical requirements for e-scooters including:

- Vehicle stability
- Structural integrity
- Alternative configurations including standing and seated e-scooters and e-scooters with 2, 3 or 4 wheels
- Battery safety
- Motor power and hill climbing ability
- Differences between rented and privately owned e-scooters

Work Package 3 Integration with vehicles for disabled people and the effect of e-scooters on disabled road users

Work Package 4 Sustainability, environmental impact and lifecycle

The key recommendations of this report are:

1. To make e-scooters accessible to the greatest range of users and improve their utility to disabled people and people with mobility impairments, future regulation should permit the design, manufacture and sale of e-scooters with (or without) seats and with 2 or more wheels.
2. Adopt practical performance-based tests for e-scooter stability based on those currently applied in Germany under the eKFV approval system.
3. Initiate an update to the structural integrity requirements in BS EN17128:2020 in order to make them more robust and more closely aligned to real-world use cases. In the interim, initiate the creation and promulgation of industry best practice guidance on the engineering of e-scooter structures.

4. E-scooters should be fitted with a system that limits their maximum speed which cannot be easily defeated.
5. Permitting e-scooters to be used on footways will bring clear accessibility benefits for those with mobility impairments. However, there are legitimate concerns that permitting e-scooters to be ridden on the footway will inevitably bring them into conflict with pedestrians, likely resulting in collisions. This is of particular concern to groups such as people with visual impairments and older people. Careful consideration must therefore be given to the relative merits of facilitating the mobility of some groups at the potential expense of the safety, perceived or real, of others. As a minimum, if e-scooters are to be permitted to be ridden on the footway, they should be fitted with a user operated control which limits their maximum speed to 4 mph, to be used while they are on the footway.
6. For the purposes of technical regulations, the laden mass of e-scooters should be regulated, rather than their unladen mass. Manufacturers should be required to declare both the unladen mass of the machine, and the maximum laden mass, in order that users are able to select machines appropriate to their needs. Manufacturers should also be required to take full account of the total mass of the machine, its rider, and any luggage they might carry, and incorporate these considerations into the design of safety critical systems of the machine. Further work is required to define the maximum mass limit that should apply to these machines, which should consider the full range of e-scooter use cases, in order to maximise their utility whilst also minimising any safety risks they may pose to their users and others.
7. BS EN 17128:2020 should be updated to contain the same battery requirements as BS EN 15194, and therefore the battery must comply with EN 50604-1:2016+A1:2021. However, at the same time, BS EN 50604-1 should undergo a thorough revision and be updated to address current shortcomings. In the interim, we recommend that DfT, or another appropriate government body, initiates the creation of a set of best practice guidelines or Publicly Available Specifications (PAS) for the engineering of e-scooter batteries.
8. The acceleration of e-scooters should be limited to a maximum of 2 m/s^2, in line with BS EN 17128:2020. Limiting acceleration of an e-scooter (along with speed and mass) is a more effective safety critical measure than implementing a power limit.
9. In order to reduce whole life carbon emissions, measures should be introduced to prolong the lives of e-scooters. These include the introduction of “right-to-repair” requirements and extending the mandatory warranty period to at least 2 years.
10. While local authorities may wish to stipulate certain technical characteristics for the scooters used in open access rental schemes, and should continue to be allowed to do so via their licensing of those schemes, we suggest there is no strong case to support different technical regulations for shared and privately owned e-scooters.

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1 Introduction

The e-scooter market has seen significant growth over the past several years. This has been brought on in part by the many public e-scooter sharing services that have begun operation in many locations internationally, as well as the increase in private e-scooter owners. A number of regulatory challenges have been encountered around how e-scooters can be operated, and there has been an increasing focus of research into the safety and sustainability of these new mobility devices.

Some countries, such as Germany, have developed bespoke regulations for e-scooters, but overall there remains considerable diversity in approaches across different markets. In the UK, e-scooters are classed as motor vehicles and therefore are subject to the associated motor vehicle regulations. In practice, it is very difficult for e-scooters to meet the type approval requirements set out in motor vehicle regulations, which in effect means private e-scooters are illegal to use in public spaces. Privately owned e-scooters are currently treated as machinery in the U.K. and are consequently regulated under the Supply of Machinery (Safety) Regulations 2008. While these regulations require e-scooters to comply with a basic level of machine safety, they make no stipulation about the safety of e-scooters when used on the road. For shared e-scooters, temporary exemptions from motor vehicle regulations have been granted by the Department for Transport (DfT) through Vehicle Special Orders (VSOs) to enable the managed roll-out of rental e-scooter trials across the UK – an initiative led by the DfT to gather critical data on e-scooter uptake, usage and safety to inform the development of future regulations. Privately owned e-scooters, however, are not included in the scope of these trials and thus currently remain illegal for use in public spaces.

The DfT commissioned TRL and its sub-contractor Warwick Manufacturing Group (WMG), University of Warwick, to investigate certain aspects of the safety, accessibility and sustainability of e-scooters with a view to informing the development of technical regulations that would permit privately owned e-scooters to be used in public places at some point in the future. The DfT's objectives are to ensure that if e-scooters are permitted to operate on public roads and traffic environments, they are as safe, sustainable, and inclusive as practicable. The overall objective of this project is therefore to build the evidence base and formulate proposals to aid DfT in devising a legal framework for e-scooters that will be proportionate, effective, enforceable, and responsive to innovation.

This report documents the investigations and experimentation that was conducted by TRL and WMG in the course of this project. The project was separated into four main work packages:

Work Package 1 Review of literature and international regulations and standards

Work Package 2 Analysis of technical requirements for e-scooters including:

- Vehicle stability
- Structural integrity
- Alternative configurations including standing and seated e-scooters and e-scooters with 2, 3 or 4 wheels

- Battery safety
- Motor power and hill climbing ability
- Differences between rented and privately owned e-scooters

Work Package 3 Integration with vehicles for disabled people and the effect of e-scooters on disabled road users

Work Package 4 Sustainability, environmental impact and lifecycle

The structure of this report does not attempt to replicate this work package structure. The discussion of vehicle configuration and its interaction with existing regulations for L-category vehicles and those specifically designed for disabled people has been incorporated into a single chapter since there is significant overlap between these topic areas, while other topics have been given dedicated chapters of their own where appropriate.

2 Methodology

This section summarises the methodology used to gather evidence and develop recommendations for future e-scooter technical requirements.

2.1 Literature review

A literature review (Section 3) was first conducted with a focus on:

- International construction standards for (or applied to) e-scooters
- Research that advises construction standards – current research on specific elements of e-scooter design and construction that increases safety of the vehicles.
- Collision and defect reports – evidence of e-scooter collisions and defects that can be used to draw insight into guiding relevant technical requirements.

Using a pre-defined set of search terms, we undertook an iterative search of the TRID, ScienceDirect and GoogleScholar databases, along with the websites of the British Standards Institution (BSI), International Organisation for Standardisation (ISO), German Institution for Standardisation (DIN), and American National Standards Institute (ANSI). A general search was also conducted in Google to identify relevant grey literature or other sources not available through the main databases. The literature review was conducted in two rounds, with the first being conducted at the start of the project to inform the later work packages and the second being conducted at the end to capture any additional sources of evidence that emerged since the time of the first review

2.2 Stakeholder engagement

Stakeholder consultations also formed a crucial part of the project activities. Consultations involved engaging industry stakeholders to gather key insights and perspectives. The scope of this project, and the range of stakeholders, necessitated a diverse approach to stakeholder engagement. The primary method used, where appropriate, was holding workshops. This provided an efficient method of canvassing a wide range of stakeholders. Initially, separate workshops were held with industry bodies and associations, and with representatives from disability charities. These stakeholders were then brought together at the end of the project in a set of final ‘review workshops’ to gather additional feedback and comments on the findings and draft recommendations.

In addition to workshops, representatives of e-scooter manufacturers, operators and retailers were engaged with through individual interviews. This facilitated an open and transparent discussion around potential regulations, as no competing companies were involved in the same discussion. This allowed detailed technical conversation around topics such as e-scooter design, manufacturing and testing processes. The interviews were undertaken by two or more experienced senior TRL researchers. A set of high-level questions were asked, but with flexibility to enable focus on particular areas of knowledge or interest held by interviewees. A summary of the key findings from the stakeholder engagement is provided in Section 4, and the insights have been considered throughout the project as part of wider investigations into the various topics.

2.3 Analysis of structural integrity requirements

Building on the broader literature review, a detailed review and assessment of the structural integrity requirements specified in BS EN 17128:2020 and BS EN 15194:2017 was undertaken. The objective was to examine the types of tests specified, the precise outcomes these tests aim to achieve, and the performance criteria they adhere to. The rationale behind this approach was twofold: first, to gain a comprehensive understanding of the current benchmarks for structural integrity in e-scooters, and second, to ascertain how robust these requirements are in comparison to EAPCs. This analysis served as a basis for developing recommendations for the technical requirements of e-scooters.

2.3.1 Comparison criteria

The comparison of the structural integrity tests and requirements for e-scooters and e-bikes was based on criteria selected to align with the structure established in BS EN 17128:2020 for e-scooters and BS EN 15194:2017 for e-bikes. This alignment ensured that the comparison was both relevant and comprehensive, addressing the core aspects of structural integrity as defined in these standards. The criteria were as follows:

Areas of focus: This criterion centred on identifying and comparing the parts of e-scooters and e-bikes subjected to structural integrity testing. The focus was on pinpointing the areas deemed crucial for maintaining structural integrity across both vehicles, such as the handlebars and frames, ensuring a comprehensive understanding of where each vehicle type might face the most stress or potential failure.

Testing protocols, methodologies and parameters: This criterion encompassed an evaluation of the testing protocols for e-scooters and e-bikes, integrating an analysis of the types of tests (such as impact resistance and fatigue endurance), the methodologies and procedures employed, and the levels of force applied. The focus was on comparing the technical parameters and approaches used in testing similar components of both e-scooters and e-bikes, thereby offering insights into the rigour, relevance, and robustness of the structural integrity tests.

Requirements: This part of the analysis involved an examination of the pass/fail criteria for various tests conducted on e-scooters and e-bikes. This analysis aimed to compare the safety and quality standards across both vehicle types, determining if these criteria ensure equivalent levels of safety and reliability.

2.4 Review of stability standards and test specifications

A detailed review was conducted of the German eKFV micromobility approval regulations, the Spanish Manual of Characteristics of Personal Mobility Vehicles and BS EN 17128:2020 in order to identify the methods by which the stability of e-scooters is specified in other national jurisdictions and the relevant standard.

2.5 Market reviews

Two market reviews were undertaken. The first explored the diversity of e-scooter models available for purchase with a particular focus on identifying 2, 3 and 4 wheeled variants and those with and without seats; the result are summarised in Section 5.1.1. The second review explored the range and diversity of the mobility scooter market and its overlap with the e-scooter market. Manufacturer websites, retail outlets and e-commerce platforms were examined; the review was not exhaustive but intended to identify example models of mobility scooter which illustrate the broad spectrum of devices available for purchase in the UK. The results from this are summarised in Section 5.2.1.

2.6 Engagement with disabled people

A series of interviews were undertaken to capture insights from disabled people. Specifically, these interviews sought to ascertain an understanding of the potential demand for e-scooters among disabled people, along with their needs and challenges around e-scooter usage. Twenty people were interviewed; five males and 15 females, aged between 26 and 66 years old. The recruitment process ensured a broad spectrum of different disabilities and health conditions were captured within those interviewed. The list below details the range of disabilities, as reported by those interviewed:

- Mobility issues (unspecified), including the need to use a wheelchair
- Arthritis, including chronic, rheumatoid, psoriatic, osteoarthritis, and polyarthritis/
- Mental health conditions, including depression, autism, and anxiety
- Partial deafness
- Spinal problem (unspecified)
- Spinal stenosis
- Cerebral palsy
- Multiple sclerosis
- Shoulder impingement syndrome
- Chronic obstructive pulmonary disease (COPD)
- Lupus
- Fibromyalgia
- Crohn’s disease
- Long covid syndrome
- Hydrocephalus
- Insulin-dependent diabetes

Each interview lasted approximately 45 minutes, with questions being asked from a topic guide (Appendix B) to explore general attitudes towards e-scooters, experiences and design needs from the perspective of a potential user, and experiences and design needs from the perspective of another road user (i.e. pedestrian, car driver). A team of three TRL behavioural researchers conducted interviews individually and extracted key themes from the collected data. The team then collated and discussed these as a group to reach a consensus on the findings. These findings are presented in Section 4.4.

2.7 Hill climb testing

Real world vehicle performance testing was completed on a number of e-scooters with a range of claimed power ratings. Objective and subjective outputs from the tests were used to assess acceleration and hill climbing capability of the vehicles, to understand the relevance of existing standards and regulations covering power and acceleration of e-scooters, and vehicles in adjacent categories.

This testing served as a basis for developing recommendations for the maximum performance limits of e-scooters, and the supporting test methodology for ensuring a consistent approach to defining and assessing these limits.

2.8 Battery safety

Existing legislation and standards applicable to e-scooters and their batteries have been reviewed and compared with those applicable for closely related products such as e-bikes. The safety requirements in the legislation and standards have been examined in the context of real-world incidents and of Lithium-Ion battery failure modes and the state-of-the-art in protective measures.

2.9 Sustainability assessment

Best- and worst- case environmental performance of shared-use and privately owned e-scooters have been quantified through life cycle assessments (LCA). The methodologies used have been developed and applied to other forms of transportation over several years, with additional information relevant for e-scooters gained from literature reviews and stakeholder consultation. The best-case scenario provides an aspirational target for the environmental performance of e-scooters, with quantified and considered recommendations targeted at reducing carbon emissions through the product life cycle and value chain, or extending serviceable life of the vehicle to reduce carbon emissions per passenger, per kilometre travelled.

3 Literature review

This chapter contains the output of the first work package – a review of literature and international regulations and standards relevant to e-scooters. The objective of this literature review was to help provide an understanding of the current construction standards being used by other countries, and any research which has been conducted to inform the development of construction standards. The findings drawn from this evidence review enable an initial assessment of which technical requirements already have a strong evidence base for inclusion in future construction standards and which required further investigation in the subsequent stages of this project.

The chapter is structured as follows:

- Section 3.1 details the method used to undertake the evidence review.
- Section 3.2 provides a discussion of the findings drawn from the evidence review.
- Section 3.3 summarises the main conclusions, recommendations for the construction standards, and identified research gaps

3.1 Method

In order to identify the current state of the art with regard to e-scooter construction standards, the evidence review focused on the following elements:

- International construction standards for (or applied to) e-scooters – standards currently being used by other countries.
- Research that advises construction standards – current research on specific elements of e-scooter design and construction that increases safety of the vehicles.
- Collision and defect reports – evidence of e-scooter collisions and defects that can be used to draw insight into guiding relevant technical requirements.

A set of search terms (Appendix A) was generated to target these three elements. An iterative search process using these terms was conducted across a selection of appropriate online research databases; TRID, ScienceDirect, and GoogleScholar. Websites for a range of standards authorities were also searched, including: British Standards Institution (BSI), International Organisation for Standardisation (ISO), German Institution for Standardisation (DIN), and American National Standards Institute (ANSI). Lastly, Google was also used to run searches in an effort to identify relevant grey literature or other sources not available through the main databases. As an added step, the search region of Google was repeatedly changed when running searches to support the identification of international literature and standards. The literature review was conducted in two rounds. The first round was completed at the start of the project to inform the later work packages. This first search resulted in the following cumulated literature:

- Six construction standards
- Five government reports detailing collision data

- Seven industry reports and articles
- 21 academic journal articles

After including the eight TRL case study projects which acted as a starting point for this review, the 47 total documents were collected in a spreadsheet for scoring and review for the first round of the literature review. The second round was conducted at the end of the project to identify any additional key sources of evidence that have emerged since the time of the first review. The same approach was taken to the search during this round, which identified four additional papers. This included the Spanish e-scooter construction standard, ‘Manual of characteristics of personal mobility vehicles’, and three academic journal articles.

Sourced academic literature and industry reports were scored on a set of inclusion criteria (see Table 1). Only the highest scoring literature (i.e. those that had a total score across the criteria of either eight or nine) was considered for full-text review and inclusion in this report. This scoring process ensured that only the most up-to-date, relevant, and high-quality evidence was included in the review.

Table 1: Inclusion criteria for the review of literature

Criteria	Score = 1	Score = 2	Score = 3
Relevance	Not relevant to the objectives	Some indirect relevance to the objectives	Directly relevant to the objectives
Quality	Non-scientific article (e.g. online source, newspaper, or magazine article)	Evidence review / case study investigation	Formal legislative documentation, including published guidance / recommendations from relevant groups (e.g. PACTS) OR, Scientific peer-reviewed article
Timeliness	Published over 5 years ago	Published between 3-5 years ago	Published within the past 3 years

Only one of the industry reports was excluded as a result of inclusion scoring. Of the 24 academic journal articles, only six scored sufficiently high on the inclusion criteria to be included in the review. Those that were not included typically failed on the scoring criteria due to being considered outdated and/or not relevant to the aims of the current work. It was identified that the majority of research regarding e-scooter regulations primarily relates to the implementation and usage of these devices, with seemingly little attention being given to defining construction standards. This may be due to the difficulty that some countries and authorities have faced in catching up with the rapid development in e-scooter technology. In some cases governments remain in a position where they are still trying to determine what standards and regulations need to be put in place for this new mode. The lack of identified evidence on this topic confirms there is a considerable research gap. In addition, no information relating specifically to e-scooter defect reports was identified. Collision data reports are also considerably limited due to generally poor reporting and recording of e-scooter incidents. Given the pressing need to understand and establish construction standards for e-scooters, further investigation is evidently warranted. The current programme of research is intended to take a significant step in filling this research gap.

Excluding the low-scoring evidence, the final collection of literature included 30 different items. These were reviewed in full, with summaries of relevant information being collated in the review spreadsheet. The findings from this review of evidence are discussed in the following section.

3.2 Findings

This section has been separated into three subsections. The first (Section 3.2.1) collates and summarises relevant evidence from four case studies of previous TRL research which has explored the topic of e-scooter regulations; the second (Section 3.2.2) explores existing e-scooter construction standards and any research that contributes to defining such standards; and the third (Section 3.2.3) details evidence around collision data to understand safety needs that should be considered in defining e-scooter construction standards.

3.2.1 TRL case studies

In 2019, TRL completed an extensive evidence review for the Road Safety Authority (RSA) in Ireland (Hitchings, Weekley, & Beard, 2019). This review sought to identify international best practice in the regulation of electric personal mobility devices (including e-scooters) and understand the associated safety implications. To supplement the review of published literature, 12 countries which were felt to have more developed legislation on the use of these devices were investigated to understand their approach to regulating their use. It was clear from the case study investigation that no clear consensus as to how to approach legislating personal mobility devices had been reached, with considerable variation in how different countries regulate their use. This included variations in power and speed limits, use of helmets, and locations in which they could be operated. This work concluded with a series of recommendations on how the RSA could develop policy and legislation around electric personal mobility devices. These recommendations included developing clear classifications for these devices, guidance around their safe use, and – of particular relevance to the current work – implementing minimum safety standards for these devices.

A direct follow-up to the 2019 study was completed in 2021 (Hitchings, Weekley, & Beard, 2021). This sequel study was completed in response to Ireland introducing the ‘Road Traffic (Amendment) (Personal Light Electric Vehicles) Bill’, which intended to update existing regulation surrounding e-scooters. The purpose of this work was to provide RSA with an understanding of what changes had taken place in the two years since the original study, and identify information which was still applicable to the current situation. A similar approach was taken in exploring the same set of case study countries. As minimal changes had been made in the time since the 2019 study, the findings from this work largely reaffirmed the findings of the original study. One key conclusion drawn from these works was the lack of robust and reliable data for e-scooter injuries and collisions; a problem that persists, as is discussed in Section 3.2.3.

The second TRL case study was a programme of research involving off-street e-scooter trials conducted in 2020. This programme included four separate studies. The first study was a review of national and international e-scooter standards and regulations (Wardle & Beard, 2020), similar to that conducted for RSA the year prior as well as that covered in Section 3.2.2. By gaining an understanding of e-scooter legislation, standardisation, and testing in other countries, this first study was able to inform the design of the e-scooter performance tests planned for a later stage of this programme of research. The second study (Wilford, Wardle, Jenkins & Beard, 2020) expanded on the first by understanding and defining the safety considerations required for the e-scooter performance tests, such as the operational area, speed limits, and design specifications.

Study three (Beard, Guy, Jenkins, Wallbank & Wardle, 2020) covered the off-street e-scooter performance tests that the first two studies helped to design. This included: stability tests, to understand the rider's ability to maintain stable control of the e-scooter under different operating and environmental conditions; and braking tests, to determine stopping distances of emergency stops at different speeds. These tests were performed on five different e-scooter models and a standard pedal bicycle (baseline measure) to enable assessment of different design specifications. Riding over rough surfaces and obstacles (e.g. drainage cover, raised crossing) generally only resulted in small lateral movement from the intended path of travel. However, a simulated 50 mm pothole did show some significant impacts on riding ability across all models – small, solid wheels in particular were unable to traverse the obstacle safely. Footbrakes and electronic brakes were found to have notably worse braking performance compared to mechanical brake systems. Dual-braking systems operated by a single lever also appeared to present a reduced risk compared to independent-braking systems (i.e. front and rear brakes operated via separate left- and right-hand levers on the handlebars). The independent-braking system often resulted in the rear wheel lifting off the ground when performing a stop at higher speeds (>20km/h).

Closing out this four-part programme of research, the final study performed a review of evidence to determine whether riding e-scooters can be classified as 'active travel' (Beard, Lawson & Jenkins, 2020). This review explored the physical and mental health impacts of riding an e-scooter. There was a lack of literature on both points; however, it was concluded that a reasonable assumption could be made that using an e-scooter offers more exercise than standing or riding a bus. In addition, the positive experience of riding has the potential to have positive impacts on mental well-being, although ultimately more evidence would be required to determine whether it can truly be considered 'active' and quantify the benefits of e-scooter riding. Considering this work as a whole, there are useful findings that can contribute to the current investigation on e-scooter construction standards; in particular, the evidence around brake and wheel considerations drawn from study three. These are discussed in Sections 3.2.2.4and 3.2.2.5respectively.

In 2021, TRL conducted an extensive study for the European Commission in the market development and safety of personal mobility devices and L-category vehicles (including e-scooters) (Guy et al., 2021). This work included an analysis of the market and the influence of existing legislations at the EU and national level, an evaluation of available accident data involving these vehicle types, and the provision of a series of recommendations for minimum safety technical requirements. One of the primary conclusions of this work is the recommendation to devise a dedicated system for the harmonious approval of personal mobility devices that is separate from current regulations (EU No. 168/2013). In other words, the study presents the justification for the current investigation. In addition, some specific recommendations were proposed around construction standards of these devices. First, is to increase the power limit of personal mobility devices from 250W to 1000W, because this would allow sufficient power for most designs and configurations of vehicle. And second, is to increase the speed limit of these devices to 30km/h to align with speed limits being used in many urban areas. These points around speed and power limits are discussed further in Sections 3.2.2.1and 3.2.2.2respectively.

The last TRL case study to be discussed is a recent review of e-scooter policy and regulation (CPC & TRL, 2022). Policy and regulatory interventions from across six countries (France, Germany, Spain, Denmark, New Zealand, and three US states) are explored, as well as literature on the impacts of these interventions on safety, environmental outcomes, economic opportunities, and society. Much like the other reviews conducted previously, this work highlighted once again the lack of robust literature and regulatory interventions across all locations under investigation. Of relevance to the current investigation, it was found that maximum speed limit applied to e-scooters ranged between 20-25km/h across locations (with the exception of one US state which featured a 40km/h speed limit). This point is discussed further in Section 3.2.2.1.

3.2.2 Construction standards

Seven construction standard documents were identified from the search of evidence. Three of which define technical specifications which are currently applied to e-scooters across Europe, Germany, the Netherlands and Spain; these details are presented in Table 2. Two cover technical specifications for electrically assisted pedal cycles (EAPCs), shown in Table 3. The final construction standard document (UL 2272) is a white paper which was produced in response to the documented risk associated with the rechargeable battery systems used in e-mobility devices (in particular, hoverboards). As such, UL 2272 largely gives focus to construction standards surrounding battery safety and so has not been included in Table 2; instead, this paper is discussed separately in 3.2.2.3. This is of particular importance as Work Package 2 of this project will give a specific focus to battery safety. Alongside the formal construction standards provided in Table 2 are industry documents that provide recommendations for regulatory requirements of e-scooters.

Table 2: Details of the regulatory requirements (construction standards) and recommendations (industry documents)

Technical element	Standard: EN 17128:2020 (Europe)	Standard: eKFV (Germany)	Standard: Dutch framework for LEV (The Netherlands)	Standard: Manual of characteristics of personal mobility vehicles (Spain)	Document: Recommendations on safety of e-scooters (ETSC & PACTS, 2023)	Document: The route to tomorrow's journey (MCIA, 2019)	Document: Micromobility L0e & L1e-C regulatory requirements (MCIA, 2021)
Max speed limit	25 km/h; Classes 2 and 4 vehicles shall be equipped with a pedestrian mode for limiting speed to a maximum of 6 km/h	6-20 km/h	6-25 km/h; maximum acceleration of 1.5 m/s^2	Maximum design speed of 6-25 km/h	20 km/h; consideration should also be given to implementing lower limits for shared e-scooters in pedestrianised zones	25 km/h for standing e-scooters; 35 km/h for seated e-scooters	25 km/h
Max continuous rated power limit	No power limit required, providing that the driving power ensures that the vehicle speed cannot exceed the maximum speed of the vehicle's class	500 W or no more than 1,400 W if at least 60 % of the power is used for self-balancing	400 W	Self-balancing vehicles: ≤2,500 W (at least 60 % of this power must be dedicated to the self-balancing system) Passenger vehicles without self-balancing: ≤1,000 W Cargo vehicles: ≤1,500 W	250 W	250 W for standing e-scooters; 500 W for seated e-scooters	500 W
Batteries	Shall be designed to avoid risk of fire, ignition, overheating, and emission of dangerous substances (gas or liquid) resulting from abnormal use	Unspecified	Unspecified	Vehicles can be equipped with batteries up to 100 VDC and with an integrated charger up to 240 VAC input; battery requirements must also comply with that specified in EN 17128:2020	Unspecified	Unspecified	Maximum battery supply voltage ≤48 V

Technical element	**Standard:** **EN 17128:2020** **(Europe)**	**Standard:** **eKFV** **(Germany)**	**Standard:** **Dutch framework for LEV** **(The Netherlands)**	**Standard:** **Manual of characteristics of personal mobility vehicles** **(Spain)**	**Document: Recommendations on safety of e-scooters (ETSC & PACTS, 2023)**	**Document: The route to tomorrow's journey (MCIA, 2019)**	**Document:** **Micromobility L0e & L1e-C regulatory requirements (MCIA, 2021)**
Brakes	Shall be equipped with at least one braking device; actuated by hand with a lever or by foot while being in a normal driving position	Must be equipped with two independent brakes which are able to brake the vehicle to a standstill, act up to a maximum speed, and achieve a deceleration value of 2.5 m/s^2	Unspecified	Shall be fitted with two independent brakes, which may be operated from the same actuator; freight or other service vehicles shall require separate actuators for each axle; brakes must decelerate the vehicle to a stop, act up to a maximum speed, and achieve a deceleration of 3.5 m/s^2; one brake should be able to exert a minimum of 44 % of the braking effect without affecting vehicle trajectory	Recommend a requirement for independent front and rear wheel braking devices	Unspecified	Unspecified
Dimensions	Unspecified	Width: 0.7 m Height: 1.4 m Length: 2 m	Width: 0.75 m Height: 1.5 m Length: 2 m	Passenger vehicle: Width: 0.75 m Height: 1.4 m Length: 2 m Cargo vehicle: Width: 1 m Height: 1.8 m Length: 2 m	Unspecified	Unspecified	Deck width: 350 mm

Technical element	**Standard:** **EN 17128:2020** **(Europe)**	**Standard:** **eKFV** **(Germany)**	**Standard:** **Dutch framework for LEV** **(The Netherlands)**	**Standard:** **Manual of characteristics of personal mobility vehicles** **(Spain)**	**Document: Recommendations on safety of e-scooters (ETSC & PACTS, 2023)**	**Document: The route to tomorrow's journey (MCIA, 2019)**	**Document:** **Micromobility L0e & L1e-C regulatory requirements (MCIA, 2021)**
No. of wheels	Unspecified	No less than two	No less than two	One or more	Unspecified; however, it is noted the most e-scooters feature two wheels set one behind the other	No less than two	Two
Wheel size	Unspecified	Unspecified	Unspecified	Minimum diameter (including tyre) of 8 " and made of a material that allows grip on the ground; under no circumstances shall the use of slick tyres be permitted.	Minimum front wheel size of 12 ” and minimum rear wheel size of 10 ”	Minimum of 8 ” for standing e-scooters; minimum of 10 ” for seated e-scooters	Minimum of 8.5 ”
Structural integrity (including handlebars and frame)	Device shall be structurally sound with no hazardous edges/ corners/ protrusions/ moving parts, and recommendation to reduce vibrations	Unspecified	Unspecified	Applying procedures described in EN 17128:2020, the vehicle should show no fractures or permanent deformations	Statement of 'fit for purpose' by manufacturer	Unspecified	Shall be sufficiently robust to withstand their intended use (including maintenance and adjustments) over their normal lifetime; the manufacturer shall provide a statement to this effect

Technical element	Standard: EN 17128:2020 (Europe)	Standard: eKFV (Germany)	Standard: Dutch framework for LEV (The Netherlands)	Standard: Manual of characteristics of personal mobility vehicles (Spain)	Document: Recommendations on safety of e-scooters (ETSC & PACTS, 2023)	Document: The route to tomorrow's journey (MCIA, 2019)	Document: Micromobility L0e & L1e-C regulatory requirements (MCIA, 2021)
Structural integrity (including handlebars and frame)	Device shall be structurally sound with no hazardous edges/ corners/ protrusions/ moving parts, and recommendation to reduce vibrations	Unspecified	Unspecified	Applying procedures described in EN 17128:2020, the vehicle should show no fractures or permanent deformations	Statement of 'fit for purpose' by manufacturer	Unspecified	Shall be sufficiently robust to withstand their intended use (including maintenance and adjustments) over their normal lifetime; the manufacturer shall provide a statement to this effect
Lighting	Most important safety requirement is not to see during night use (or tunnels) but be seen from other traffic users	Lighting equipment (which includes phosphors and reflecting agents) must meet existing requirements of the Road Traffic Licensing Regulations	Unspecified	Shall be equipped with front (white), both sides (white or yellow) and rear (red) reflectors; must also be equipped with a lighting system at the front (white) and rear (red); cargo vehicles shall be fitted with yellow side reflectors and red rear reflectors on the edges and corners of the load and require both front and rear direction indicators	Independent front and rear lighting; consideration should also be given to implementing the use of indicator lights to reduce the need of performing hand signals while riding	Must be fitted with lighting and signalling devices	Must be fitted with lighting and signalling devices

Technical element	Standard: EN 17128:2020 (Europe)	Standard: eKFV (Germany)	Standard: Dutch framework for LEV (The Netherlands)	Standard: Manual of characteristics of personal mobility vehicles (Spain)	Document: Recommendations on safety of e-scooters (ETSC & PACTS, 2023)	Document: The route to tomorrow's journey (MCIA, 2019)	Document: Micromobility L0e & L1e-C regulatory requirements (MCIA, 2021)
Audible warning signal	An audible device, controlled by a command on the device handlebar, shall be provided to allow a warning to be given to persons in the vicinity of the vehicle	Must be equipped with at least one audible warning signal	Unspecified	Shall be equipped with an audible warning device that complies with the requirements set out in EN 17128:2020; cargo vehicles also require an audible reversing warning	Must be fitted with an audible warning device	Unspecified	Must be fitted with an audible warning device
Additional points of note	Harmonised with the EU Machinery Directive (2006/42/EC), implemented in Great Britain via The Supply of Machinery (Safety) Regulations 2008	A steering or handrail of at least 700 mm (500 mm for those with a seat)	None	For self-balancing vehicles fitted with a seat, the seat reference point shall be 540 mm; handlebars shall have a minimum height of 700 mm (this may be reduced to 500 mm for self-balancing seated vehicles); vehicles with <3 wheels shall be fitted with a stabilisation system for use while parked (i.e. a kickstand")	Must be fitted with anti-tampering mechanisms and two independently-operated braking devices (one acting on the front wheel and one acting on the rear wheel)	None	Must be fitted with anti-lock and combined brake systems, as well as anti-tampering measures

Unless otherwise unspecified, it can be seen from the above details that there are no significant differences between the different construction standards. Any differences that do exist appear only marginal; for instance, the specifications for device width and height only differ by 0.05 m and 0.1 m respectively between the German and Dutch standards. However, these minor differences in fact equate to a major market impact, in that a product built to the maximum Dutch dimensions could not be sold in the German market. Thus, trade barriers are being created without any clear justification.

The formal construction standards are also largely supported by industry reports which have recommended similar specifications. One element with notable differences across the documentation is the maximum continuous rated power limit. The ETSC and PACTS (2023) and MCIA (2019) industry reports recommend a limit of 250 W (and in the case of the latter, 500 W for seated e-scooters), the Dutch framework specifies a limit of 400 W, while the German framework and MCIA (2021) report state a 500 W limit. It is worth noting that EN 17128:2020 does not specify a power limit as "*limiting the power of a self-balancing vehicle risks the inability [sic] to find the balance at any moment*" (p.73). In addition, this standard explains that e-scooters – being designed to be portable and as such being limited in the size of batteries and motors which can be fitted – are naturally limited in their maximum power. For these reasons, EN 17128:2020 justifies no formal power limit. The reasoning applied here does not seem to be robust, since EN17128:2020 does not specify a weight limit either, thus the weight, and therefore by the logic of the standard, power of the machine is limited only by what somebody might be prepared to transport, which evidence from the mobility scooter industry suggests could be 150kg or more.

It is also worth noting the industry reports have made recommendations for minimum wheel sizes of e-scooters, a design element which has not been specified in any construction standard. It is unclear why this element has not been included in construction standards as yet, because there is evidence (see Section 3.2.2.5) to suggest that an e-scooter's wheel size can have an impact on the safety of the device.

With regards to the European standard, EN 17128:2020, the UK voted against its approval based on concerns that it does not seek to improve safety and is deficient in a number of areas (including battery safety), even going so far as to recommend changes to clauses felt to be inconsistent with the rest of the standard. This being understood, the current review will look to answer whether these are sufficient reasons for the DfT to justify not adopting the EN 17128:2020 standard in the UK.

In addition to that outlined in Table 2, some e-scooter manufacturers have also stated that they have adopted construction standards for electrically-assisted pedal cycles (EAPCs) to set the performance criteria for their e-scooters. It is worth noting that these standards for EAPCs are in turn built upon existing standards for bicycles. Two standards relating to bicycles and EAPCs are presented in Table 3.

Table 3: Details of the regulatory requirements of bicycles and e-bikes (as e-scooters are fundamentally different in design from bicycles, details on dimensions, wheel size, and mass have not been included in this table)

Technical element	Bicycles: ISO 4210	E-Bikes: EN 15194:2017
Max speed limit	Unspecified	The electrical motor shall offer assistance up to 25 km/h or lower
Max continuous rated power limit	Unspecified	250 W
Batteries	Shall be designed to avoid risk of fire and mechanical deterioration resulting from abnormal use; charging systems must be designed to prevent overvoltage, overheating, hot disconnect, and short circuiting	Shall be designed to avoid risk of fire and mechanical deterioration resulting from abnormal use; charging systems must be designed to prevent overcharging, and appropriate overheating and short circuit protection shall be fitted
Brakes	Unspecified	Shall be equipped with at least two independently actuated braking-systems, one acting on the front wheel and one on the rear wheel; braking systems shall operate without binding
No. of wheels	Two	Two
Structural integrity	Shall be sufficiently robust to withstand their intended use (including maintenance and adjustments) over their normal lifetime	Shall be sufficiently robust to withstand their intended use (including maintenance and adjustments) over their normal lifetime
Lighting	Shall be equipped with lighting (front and rear) and reflectors (front - white, rear - red, side – white or yellow, and pedals - yellow) in conformity with the national regulations in the country in which the bicycle is marketed	Shall be equipped with lighting (front and rear) and reflectors (front - white, rear - red, side – white or yellow, and pedals - yellow) in conformity with the national regulations in the country in which the bicycle is marketed
Audible warning signal	Where a bell or other suitable device is fitted, it shall comply with the provisions in force in the country in which the product is marketed	Where a bell or other suitable device is fitted, it shall comply with the provisions in force in the country in which the product is marketed

The two bicycle construction standards align on all factors aside from speed and power limits where ISO 4210 does not specify any requirements for these elements. When looking at these requirements specified by EN 15194:2017, the speed and power limits align with the recommendations for e-scooter standards proposed by MCIA in 2019. However, it must be borne in mind that EAPCs are powered jointly by the electric motor and the rider, while e-scooters are driven exclusively by the electric motor (with the exception of the kick start).

The following subsections discuss the evidence around how these different technical elements should be regulated, and how well the current standards shown in Table 2 and Table 3 align with this evidence.

3.2.2.1 Speed limits

Following the consultation of the UK rental e-scooter trials, a requirement has been specified in the country that rental e-scooters have a maximum speed not exceeding 15.5 mph (25 km/h). This appears to be the common standard, because it aligns with the recommendations put forth by MCIA (2019; 2021), as well the Dutch and Spanish frameworks and EN 17128:2020. ETSC and PACTS (2023) on the other hand recommends a maximum speed limit of 20km/h which aligns with the German eKFV standard. They base this on crash test data performed by the MAPFRE Foundation, which showed considerable risk of injury to both the rider and any pedestrian that might be hit compared to lower speeds. In addition, PACTS (2022) explains that an operating speed of 20 km/h is higher than the average speed of many pedal cycles in urban areas. Lower speed limits of 6km/h (EN 17128:2020) and 10 km/h (PACTS, 2022) have also been recommended for pedestrianised zones, though enforcement of such speeds would likely be reliant on police resources and therefore difficult to implement. Meanwhile, Guy et al. (2021) suggests increasing the speed limit to 30 km/h to align with speed limits being used in many urban areas, though they recommend that this be partnered with careful monitoring to ensure the higher limit does not lead to an increase in casualties.

The difficulty in specifying a requirement for the maximum speed limit of e-scooters comes from their ability to operate in traffic environments of differing speeds, both alongside pedestrians and motorised transport. E-scooters must therefore be able to travel sufficiently fast to operate alongside the latter, which in turn creates a safety risk when allowed to operate alongside the former.

Given the inconsistency in standards and recommendations, as well as the lack of evidence providing recommendations on appropriate speed limits for e-scooters, it is difficult to draw any reliable conclusions on this element. Unless e-scooters are restricted only to a single environment wherein a requirement can be specified to match that of existing traffic in that environment, there may yet continue to be a challenge in creating a safe optimal standard for e-scooter speed limits.

3.2.2.2 Power limits

With regards to limits on an e-scooter’s continuous rated power, current standards, regulations and recommendations largely specify a range between 250 W to 1,000 W (see Table 2). The 500 W limit is also what is required of rental e-scooters in the UK (Transport Committee, 2020). This 250-500 W range has also been observed in the regulatory requirements many countries have enforced around the operation of e-scooters (Hitchings et al., 2021). However, there are some exceptions.

Specifically, EN 17128:2020 does not require a maximum power limit, but does specify a maximum acceleration value of 2 m/s^2. The stated justification being that the size and portability of e-scooters naturally limits the size of the batteries and motors that can be fitted which in turn limits maximum power that these devices can have, which, as noted above, lacks robust engineering validity.

If a power limit is to be used, our previous work for the European Commission suggests a larger power limit is appropriate. We explained that the 250W limit which has been applied to many e-scooters aligns with that applied to EAPCs (PACTS, 2022), as is applied in EN 15194:2017 (see Table 3). However, EAPCs are supported by the rider's pedalling and consequently have significantly more than 250 W of power available at the wheel and can therefore manage to climb steep gradients and travel at speeds faster than 25 km/h without electric motor assistance. Unlike EAPCs, e-scooters have no human assistance and rely entirely on the motor to propel the vehicle (once in motion). In our 2021 report to the European Commission we recommended a power limit of 1,000 W for all forms of personal mobility device including e-scooters which would allow sufficient power for most e-scooter designs and configurations. This recommendation was based on an analysis of the power requirements of a variety of personal mobility devices including cargo bikes and is intended in part to resolve categorisation issues at the bottom end of Regulation (EU) No 168/2013. This power limit is however conditional on the robust application of built-in speed limitation devices and appropriate measures to ensure acceptable controllability, particularly under acceleration.

There would therefore appear to be some evidence to support having a maximum power limit greater than 250 W. Limiting the maximum power of the device to some extent limits the maximum speed of the device while also limiting the ability of the vehicle to reach an adequate speed when climbing a gradient or riding into a headwind, both of which are undesirable consequences. Regulating the power and speed limits at the construction level is considered one way to ensure compliance with specified limits, easing the burden on police enforcement (PACTS, 2022). Any specified power limit must factor in the expected use of e-scooters, including where they are likely to operate (e.g. on roads, pedestrianised zones), associated speed limits, as well as easing the burden on enforcement. The concept of a power limit, whether one is appropriate, and what other safety requirements could be put in place instead will be explored as part of Work Package 2, which shall seek to generate a strong evidence base on the recommended minimum technical requirements for e-scooters in the UK context.

3.2.2.3 Batteries

As mentioned at the beginning of Section 3.2.2, one of the identified construction standard documents, UL 2272, gave specific attention to battery safety. This white paper details the demonstrable fire safety risk associated with hoverboard devices, with 52 fires being attributed to these devices between mid-2015 and February 2016. Part of the reason behind this issue was the improper certification marks given to hoverboards – with product packaging showing testing and certification marks for individual components of the device, but not for the device as a whole. UL 2272 explains that while safety testing of the types of power systems used in e-mobility devices has been in place for many years, these may not perform as expected when combined with other components in a given application.

UL 2272 therefore proposes a system-level approach, rather than a component-level approach, to safety testing e-mobility devices. Specifically, they specify a series of electrical safety tests assessing:

- Overcharge
- Short circuit
- Over-discharge
- Temperature
- Imbalance charging
- Dielectric voltage
- Leakage current
- Grounding continuity
- Isolation resistance

These tests align with the requirements specified in EN 17128:2020. E-mobility manufacturers are expected to have certification of these tests on their products. Those that are compliant with the requirements of UL 2272 will be given a specialised holographic mark to evidence their certification. These specialised marks will also help to counter counterfeit safety marks which were found to contribute to the aforementioned fire incidents.

In addition to the above safety testing requirements specified in UL 2272, the EU has also established a new regulatory framework for batteries (EPRS, 2021). This framework aims to introduce mandatory requirements on the sustainability (e.g. carbon footprint rules, performance and durability criteria), safety, and end-of-life management of batteries. These changes, planned to apply from as early as 2024, would apply to the batteries used within e-mobility devices such as e-scooters.

Although most of the construction standards and industry reports summarised in Table 2 do not provide any specifications on battery requirements, it is clear that consideration should be given to this element of e-scooter design. In particular, the standard set out in UL 2272 provides the minimum requirements on which battery safety should be tested.

3.2.2.4 Brakes

Unless otherwise unspecified, standards and industry documents specify a requirement for at least one (EN 17128:2020) or two independent braking systems (eKFV; EN 15194:2017; ETSC & PACTS, 2023). During our off-street e-scooter trials (detailed in Section 3.2.1), it was observed that triggering both brakes together reduced the risk of having the rear wheel lift off the ground when undergoing harsh braking at faster speeds (≥20 km/h). This might suggest a risk associated with independent braking systems. It may therefore be necessary to include a braking test as part of the technical requirements that considers these types of occurrences. This type of test is already included in EN 17128:2020.

To complement the work we completed for DfT, Siebert et al. (2021) conducted a series of observations and surveys with e-scooter users to investigate the ergonomics of e-scooter braking systems and the potential impact on rider safety. Specifically, the study assessed riders’ ability to identify which brake actuator was coupled with which wheel (front or rear) and their ability to ready the brake actuator. The observations were conducted in Berlin in the Autumn of 2019 through cameras mounted at three different sites where the six leading e-scooter rental service providers were active. Questionnaires asking participants (N=156) about their e-scooter usage, knowledge and adherence to safety regulations, and questions about the braking system of the e-scooter they last used were also distributed in these locations.

Only one third of questionnaire respondents were able to correctly identify the braking system of the e-scooter they had last used, suggesting a lack of a simple mental model for e-scooter braking systems. In addition, across the 2,082 observed riders, it was determined that a left-hand brake lever is readied significantly more often than a right-hand lever, which in turn is readied more often than a footbrake. Siebert et al. reason that this is because the accelerator is typically operated by the right thumb, which could potentially impede the readying of right-hand braking.

PACTS (2022) recommend having more than one independent means of braking, arguing that this increases the effectiveness of stopping as well as stability while stopping. The requirement for independent braking systems is also specified in eKFV as well as recommended by ETSC and PACTS (2023). However, there is an argument to suggest that a single lever system is less prone to control confusion, since there is only a single lever to reach for. Such a system does however introduce a single failure point which could potentially leave the machine without any braking available. Further investigation into the safety of independent and dual-operated braking systems may therefore be justified to determine the optimal design standard which should be applied to e-scooters. However, in the absence of such a study, defaulting to a dual control system, with a separate, hand operated, lever for a brake on the front and rear wheel seems to most prudent.

3.2.2.5 Wheels

With the exception of EN 17128:2020, current standards specify that e-scooters must have no fewer than two-wheels. Devices which feature only a single wheel (e.g. monowheel, electric unicycle) fall outside of these specifications. Currently in the UK, rental e-scooters are required to have two wheels, front and rear, aligned along the direction of travel (Transport Committee, 2020). This decision was made following consultation of the UK-wide e-scooter rental trials. No requirement has been specified for private e-scooters since these fall outside the scope of the rental trials and remain illegal for use in public spaces.

As noted in the discussion of Table 2, there is no specified requirements around wheel size within the summarised e-scooter construction standards. However, there are varying recommendations put forth through industry documents. These range from having a minimum size of eight inches (MCIA, 2019), which is reportedly the most common size of e-scooter wheel (PACTS, 2022), up to 12 inches (ETSC & PACTS, 2023). The e-scooter performance tests we performed for DfT, as well as similar testing performed Strzeletz and Kühn (referred to in ETSC & PACTS, 2023), found that larger wheels showed greater stability than small wheels when traversing significant surface hazards (specifically, a simulated 50 mm pothole). Small (eight inch) solid wheels were not only found to be more unstable than larger wheels but were also prone to incurring damage when traversing the surface hazard.

This being the case, there is a reasonable rationale for including a minimum wheel size of at least eight inches within e-scooter technical requirements, however further investigation is needed to consider whether a larger minimum size should be recommended. This investigation should also consider the role of inter-related factors such as tyre composition and suspension design which, together with wheel size, have a material impact on stability of the device.

3.2.2.6 Size and mass

No evidence was identified from the review providing a rationale for any specific requirements around the dimensions or mass of e-scooters. Those specified in the German and Dutch frameworks (see Table 2) appear to largely be based on the design of traditional kick-scooters, with allowances given for the added weight of electrical and mechanical components required for propulsion and self-stabilisation. Following consultation of the UK e-scooter trials, rental e-scooters are required to have an unladen mass (including the battery) not exceeding 55 kg (Transport Committee, 2020).

It is worth highlighting that some academic studies were identified from this review around the physical design of e-scooters. Paudel and Yap (2021) used a validated mathematical model to perform a safety assessment of the most common e-scooter design parameters as drawn from 27 different e-scooter models. In particular, they assessed how the angle of the steering stem can affect rider stability and control of the device. Performing comparisons on steering pole angles between 78 o and 83 o, it was found that a greater angle provided a minor improvement in stability through shifting the device’s centre of mass. Although this difference in steering pole angle and associated improvement in stability is minimal, it may be a point worth considering in the design of e-scooters. However, it is unlikely that this single study provides sufficient justification for establishing specific requirements around steering pole angle.

Cano-Moreno, Reina, Lanillos, and Marcos (2024) also conducted a similarly limited study. Their focus was instead on the mass geometry parameters of e-scooters and how this impacted the vibrations received by the e-scooter – a factor shown to impact on rider comfort and health. Elements such as vehicle mass, speed, and centre of gravity were all found to contribute to level of vibrations received by the e-scooter. The authors suggest that lowering the mass of the scooter frame by 50 % could improve the amount of vibrations felt by more than 9 %. However, this conclusion was drawn from a simulated model of an e-scooter (albeit one that was based on a real e-scooter) and no real-world testing was actually undertaken. Although their dynamic model was qualitatively validated, the findings cannot be easily generalised across all e-scooter designs in the real world. The study does however highlight that some consideration should be given to testing the amount of vibrations received by an e-scooter and how this can be reduced as far as practicable so as to improve overall rider comfort and any negative impact on rider health.

Unlike Cano-Moreno et al.’s (2024) study, Novotny, Mollenhauer, and White (2023) did utilise real-world testing on more than one e-scooter model. Four different e-scooter models (including one seated model) underwent a series of tests – including speed, acceleration, braking, handling, stability, and manoeuvrability – across a range of different terrains and obstacles typical of riding environment. The authors proposed a series of recommended features (along with proposed values, shown in parentheses below) which were believed to have the greatest safety performance while performing low speed manoeuvres:

- Lightweight (50 lbs)
- Short wheelbase (35.25 ”)
- Long usable deck length (19.5 ”)
- Short deck height (5.75 ”)
- Large tyre diameter (11 ”)
- Adjustable steering angle (72.5-76.5 o)
- Suspension
- High ground clearance (3.25 ”)

Further testing of these proposed measurements would be required to determine their benefits and drawbacks in comparison to those presented in, for example, EN 17128:2020 which differs substantially in a number of areas such as mass and length. However, in principle, features such as suspension and higher ground clearance would likely make for a safer and more comfortable ride.

3.2.2.6 Lighting

With the exception of the Dutch framework wherein it was unspecified, lighting equipment was a requirement under all construction standards and recommended by all industry documents reported in Table 2 and Table 3. This includes both electronic lighting as well as reflectors. As detailed in EN 17128:2020, it is of greater importance that the e-scooter (and by connection, its rider) is conspicuous to other road users than it is for the rider to have visibility of the forward path. As e-scooters are largely operating in mixed mode traffic, this point is critical.

Industry reports (MCIA, 2019; MCIA, 2021; ETSC & PACTS, 2023) have also made the recommendation to consider the implementation of signalling devices such as indicator lights. The justification for this being that it would reduce the need for performing hand signals while riding, believed to create a risk of destabilising the rider and reducing control of the device. Findings drawn from the off-street e-scooter trials we performed for DfT suggest that this risk is minimal – albeit the tests performed were under controlled conditions with no moving traffic. There is currently little evidence to support mandating the requirement for indicators and signalling devices, however there could be benefits for their inclusion in e-scooter products.

There is, on the other hand, a clear need for mandatory lighting and reflecting devices to ensure the conspicuity of the device. This is of critical importance for riding at night. Janikian, Caird, Hagel and Reay (2024) highlight the need for sufficient headlight brightness, particularly in the absence of overhead artificial lighting, and how taillights (if present) are typically very low to the ground. The authors note that when an e-scooter is approached from behind by a vehicle at night, a driver may misperceive the taillight to be that of a bicycle that is farther away, thus creating a collision risk. This suggests a need for further research to evaluate taillight configurations to improve e-scooter visibility at night. Once understood, sufficient headlight, taillight, and retroreflector configurations would significantly improve nighttime visibility of e-scooters.

3.2.2.7 Audible warning signals

Audible warning signals (such as a thumb-operated bell or horn) are included as requirements across most of the identified construction standards and industry documents, excluding the Dutch framework and the MCIA (2019) report. Given the likelihood of e-scooters operating within mixed traffic environments, in particular alongside pedestrians, an audible warning device should help to reduce risks of collision by ensuring riders can clearly alert other road users to their presence. In addition, it removes the reliance on riders vocalising warnings to others which may be less clear or misunderstood. As such, it is sensible for audible warning devices to be a mandated requirement.

3.2.2.8 Other safety considerations

The reviewed documentation also raises some additional points which are worth considering. EN 17128:2020 provides specifications around the device being structurally sound. In short, an e-scooter's design should present no risk of physical injury to the user through hazardous edges, corners, protrusions, or moving parts. In addition, the device should be robust enough to not crack, fracture, or deform through normal usage over its lifetime, as is required in ISO 4210 and EN 15194:2017, as well as recommended by MCIA (2021). This point should be a facet of all e-scooter construction standards. EN 17128:2020 also highlights that – although vibration is not considered a significant hazard and the devices' electric motors typically do not generate any vibrations – manufacturers are not absolved from reducing vibration.

In addition, industry documents also recommend the need for anti-tampering mechanisms. Given the requirement for speed and power limits, it is important that steps are taken to prevent users from having the means to achieve performance levels beyond that of which the devices are designed. Although this is a recommendation that could be made for all electric vehicles, this is especially true for e-scooters considering their potential proximity to other traffic, pedestrians, and cyclists in busy urban environments.

3.2.3 Collision reports

As stated in Section 3.1, no information was sourced relating to e-scooter defect reports. Collision data information was also scarce. Where collision data is available, it is necessary to recognise that the reporting and recording of e-scooter related incidents is not up to the same standard of other vehicle modes. E-scooters are not one of the designated vehicle types collected in STATS19 and so fall under the 'Other vehicle' category. This then relies on the quality of information entered into a free text field which cannot be validated in the same way as the designated vehicle type data. Furthermore, many non-fatal, single vehicle incidents will likely go unreported as e-scooter users will have no obligation to inform the police of such collisions. These points must be borne in mind when interpreting the available collision data.

DfT's latest factsheet on reported e-scooter collisions in the UK, which is based on STATS19 data up to May 2023, provides information on the observable trends. The total number of collisions for the year ending 2022 (1,369; 12 fatalities) is broken down into casualties by age, time of day, police force area, and e-scooter trial area.

Information on injury types is also provided. The information presented by this factsheet does not allow for any conclusions to be drawn around how safety issues can be addressed via construction standards. Some trends can be drawn out, such as an increase in collision rates during peak travel times (8am and 4-5pm) and number of head injuries; however, these observations may only help to advise regulations around e-scooter use (e.g. mandated helmet use) rather than how they are manufactured.

PACTS published their own study (PACTS; 2023) in which they sought to quantify the extent to which e-scooter collisions were being reported to police. They did this by conducting a matching analysis, in six local authority areas in which rental e-scooter trials are underway, between records of patients presenting at emergency departments, police STATS19 records and TARN records. They found that only 9 % of all casualties injured in e-scooter collisions, and 26 % of seriously injured e-scooter casualties were recorded in STATS19. This pattern of reporting is in line with other transport modes. While this study was not primarily aimed at understanding mechanisms and severity of injury, it did note a higher rate of head injuries to e-scooter riders when compared to bicycles and motorcycles.

Micromobility for Europe (MMfE; 2023) has recently produced some industry-aggregated data from across shared e-scooter services (including Bird, Bolt, Dott, Lime, TIER, and Voi) in 29 European countries. They report similar issues as are present within the STATS19 data; specifically, a lack of a standardised reporting framework which allows for clear and reliable information on e-scooter incidents. Furthermore, little can be drawn out from this data on how construction standards could be developed to improve safety. However, it is worth noting that some trends can again be observed around e-scooter usage, such as there being a greater rate of incidents occurring with private e-scooters as opposed to shared e-scooters.

Data from Destatis (2023) also suggests that a significant proportion of e-scooter incidents in Germany (8,260 accidents in 2022 that resulted in personal injury) can be attributed to misuse, with 18.6 % being attributable to the incorrect use of roadways or footpaths and a further 18 % being attributable to alcohol use. This further suggests that the critical path to managing safety of e-scooters is around regulating their usage.

Although little in the way of academic evidence was found relating to e-scooter collision data, one study from the US suggests that more e-scooter fatalities and serious injuries occur at night (Yang et al., 2020). This suggests there is a need for ensuring e-scooters are designed to be conspicuous in low-light conditions via lighting and reflectors, as is specified in the standards and industry documents detailed in Table 2 and Table 3.

In the absence of robust and reliable data on e-scooter incidents that allows for some interpretation of the role that e-scooter design has, then ultimately little can be drawn from available data on how construction standards can best be developed to manage safety. That being said, it can be reasonably assumed that they should be designed to be conspicuous – especially if they are to operate in mixed traffic environments. Ensuring that e-scooters and their riders can be easily seen in all environments, especially low-visibility conditions such as at night, through lighting and reflectors should help to reduce the likelihood of being struck by other road users.

3.3 Conclusion to literature review

The purpose of this work package has been to review existing construction standards and related evidence to understand the state of the art with regard to technical requirements for e-scooters. Collision and defect reports were also considered within this review, intended to allow for further insight to be drawn on e-scooter design requirements. Four e-scooter standards and two EAPC standards were identified, coupled with previous TRL research, academic papers and a small selection of industry reports.

The following conclusions have been drawn from across both rounds of the literature review:

- **Current standards and regulations, though similar in many regards, show some inconsistency** – For example, as presented in Table 2, one national regulation has a power limit of 1,000 W, another 500 W and a third 400 W, while various organisations have recommended limits between 250 W and 500 W while the current standard requires no power limit at all. These inconsistencies are likely to have a major market impact by restricting the sale of e-scooters designed to one standard only to locations which uphold that standard.
- **Industry reports make recommendations for technical requirements not yet considered within current standards** – Some such recommendations include a minimum wheel size between 8-12 ”, depending on the source, and anti-tampering mechanisms. These elements have the potential to impact on user safety if not managed correctly, so there is arguably sufficient justification to incorporate these elements in construction standards. However, more evidence is still required to establish a minimum standard on such missing elements as there are inconsistencies across the recommendations that have been made. Care must be taken to ensure that regulations do not stifle potential innovations that may lead to superior rider experience and safety, and to ensure that unintended consequences are minimised, e.g. anti-tampering systems preventing easy maintenance thus leading to higher environmental impacts.
- **Collision data is limited and does not allow for insight to be drawn on the technical requirements of e-scooters** – There is a need to improve the quality of reporting and recording of data around e-scooter incidents. Though improvements are being made as this new transport mode becomes common, it is critical that a standardised process for reporting e-scooter incidents is established. Doing so would allow for more reliable insights to be drawn from collision data.

In spite of these conclusions, there are some considerations that can be made around the technical requirements of e-scooters. This includes:

- **Power limits of 250 W may not be sufficient for all designs and configurations of e-scooter** – Some industry reports (ETSC & PACTS, 2023; MCIA, 2019) have recommended a maximum power limit of 250 W. However, our previous work for EC suggests that more power is required in a e-scooter to allow travel in different environments (e.g. hill-climbing). We provide further investigation into power limits later in this report, including whether they are an appropriate tool to ensure safety of e-scooters.

- **Establishing a minimum wheel size could help to minimise the risks associated with small wheels** – There has been some evidence to suggest that small wheels (8 ”) have difficulty traversing surface hazards (e.g. potholes) that risk destabilising the rider. With this in mind, establishing a larger minimum wheel size for e-scooters (e.g. 10-12 ”) may help to overcome this safety risk. However, the design of e-scooters must be considered holistically, with other factors such as wheelbase, centre of gravity position, suspension design and tyre construction also being crucial to the stability of the vehicle.
- **It is critical for e-scooters to be conspicuous through effective lighting and reflectors** – Given the collision risks that can be attributed to not being seen, it is necessary to emphasise the importance of ensuring the conspicuity of e-scooters. Lighting requirements were included by all standards and industry documents, excluding the Dutch framework. This should be a requirement of all standards and it is important that the minimum required lighting is sufficient to ensure visibility of the device even in low-light conditions.

It should be noted that the UK committee voted against approval of the European construction standard for e-scooters, EN 17128:2020, as it was felt not to focus on improving safety. The conclusions drawn from this review provide some support for this decision as there are some notable gaps in the EN 17128:2020 standard. For instance, it is recommended that consideration is given to inclusion of requirements for anti-tampering mechanisms and stability performance standards. However, it is still worth recognising that EN 17128:2020 acts as a reasonable starting point for e-scooter construction standards in the UK that can be developed further.

4 Key insights from stakeholder engagement

This chapter summarises the key findings from the stakeholder engagement undertaken throughout this project. The information in this chapter does not constitute specific views, conclusions or recommendations from any specific stakeholders, but instead provides a summary of the main viewpoints and key themes which emerged from the series of discussions held with stakeholders. Information has been largely summarised at face value to outline the views expressed by stakeholders. The insights gathered have been considered during development of the recommendations, alongside other evidence gathered during this project.

4.1 Workshop with industry groups and road safety associations

4.1.1 Overview and objectives

An online workshop was held with representatives from road safety organisations and industry groups. The objective of the workshop was to share details on the activities being undertaken in this project, in order to gather initial insights from stakeholders, including references to relevant data or literature that could help inform the development of future regulation. The workshop was structured around several key topics relevant to e-scooter technical requirements; the philosophy of regulation, performance limits, battery safety, e-scooter configuration, stability, structural integrity, sustainability and tampering.

4.1.2 Philosophy of regulation

The consensus was that e-scooters should be zero emission at point of use and generally support decarbonisation. They should play a part in facilitating the integration of other transport modes, but shifting mode from walking to e-scooters should be avoided. It was also acknowledged that the UK does not have much in the way of segregated cycling infrastructure, and so regulation has a key role for managing safety risks.

4.1.3 Regulation

It was pointed out that while flexibility is important, regulations exist for a reason, for example there is a reason we have lots of regulations around cars, and while it was acknowledged that this makes them more expensive, this isn’t a reason in itself for not regulating for safety. It was argued that regulation should ‘raise the bar’ for all e-scooters, and the removal of cheap e-scooters from the market may be a good thing for safety. However it was also raised that while the manufacture and sale of bicycles is regulated, there is little regulation applying to their use. It was also argued that sight shouldn’t be lost of the fact that there are often sustainable alternatives to e-scooters, for example walking, cycling or taking the bus. Finally, it was noted that care should be given in relation to the blurring of edges between e-scooters and mopeds.

4.1.4 Speed

Low speed limits were recommended for a wide range of safety reasons, including aligning with 'Vision Zero' aspirations and the desire to increase social mobility through the transformation of urban areas via the introduction of low speed zones. It was raised that no European country has allowed e-scooters to have a speed limit of more than 25 km/h. If e-scooters aren't able to go up hills at their top speed this was not seen as a problem, but consideration was given to what a practical minimum speed for a hilly city should be to avoid issues around stability, particularly in the vicinity of other traffic. The relationship between speed, stability and wheel size was acknowledged, and the suggestion was made that there should be minimum wheel sizes for different speed regimes.

4.1.5 Performance limits

It was recognised that one performance limit for all types of e-scooter was unlikely to be appropriate and that different categories may be needed, with specific power limits for each. Power in itself was suggested as being something that is difficult to test or legislate for. Power was debated as a method of setting performance limits, as was limiting acceleration, which was widely supported as something that should be given consideration. Acceleration is controlled on buses and unladen trucks, so is an established method of limiting performance. A torque to weight ratio was also suggested.

4.1.6 Stability

It was highlighted that e-scooters are inherently unstable and rely on the rider to keep them stable. The number of wheels were said to have a massive effect on stability, and the addition of a seat even more so, as it couples the rider to the vehicle and lowers the centre of mass. This would impact on the level of skill needed to ride any e-scooter with it considered easier to rider a device with more than two wheels and with a seat. In addition to the number of wheels the ability of a scooter with more than two wheels to tilt was raised as being important to stability.

It was also suggested that one of the most risky manoeuvres e-scooter riders were expected to execute was lifting their hand off the handlebars to signal, particularly a problem in the case of the throttle hand.

Wheel size was also identified as being a significant factor for stability, as the mass of an e-scooter is so low, so if it has small wheels and drops into a pothole it is likely to be greatly impacted. Increasing wheel size impacts on the overall geometry and therefore what sort of road surfaces you can ride over. However, it was also pointed out that bigger wheels will compromise storage and portability. Some felt wheel size would be an attractive thing to regulate as it is straightforward to measure and enforce.

4.1.7 Structural integrity

It was raised that some e-scooters in the rental schemes had seen safety issues due to poor structural integrity; with reference to some instances of scooters handlebar stems snapping.

There was also discussion around the availability of standards, and the fact that they were mostly voluntary for e-scooters, allowing small manufacturers to get products to market quickly using self-certification.

4.1.8 Battery safety

It was thought that fires related to charging are often caused by using different or incorrect chargers to those that should be used with a given e-scooter. As a result, it was suggested that products need to be designed for foreseeable misuse, as it can be hard to change behaviours. Mandatory standards were thought to be the best approach, as long as they could be subject to flexibility and review if future batteries become safer. The EN50604-1 light electric vehicle battery standard was given as an example of a standard that could become mandatory.

4.1.9 Tampering

It was highlighted that addressing tampering of e-bikes has been difficult to incorporate through legislation, and that the issue cannot be entirely solved through technical solutions alone – legislation and enforcement are also critical.

The downside of taking a technical approach to anti-tampering is that this can limit innovation, the right to repair and the ability to access spare parts – negatively impacting sustainability and longevity. A desire for higher speeds was considered as the main reason e-scooters were tampered with. It was felt this could be addressed in part by limiting the power of the scooter, but acknowledged that there would be other implications of this, as also discussed above.

4.1.10 Sustainability

Carrying out a life cycle assessment of scooters was floated as one method of ascertaining their sustainability, using ISO standards on LCA. It was pointed out that it is difficult to establish how far e-scooters travel in their life, and it was felt by some that distances may be low overall.

Another suggestion was to look at supply chain sustainability, or looking at the EU critical raw materials act in the context of e-scooters, although this was thought to potentially be a big ask. Other thoughts included registering with the environmental national waste packaging database from the Environment Agency, giving e-scooters efficiency labels as with household appliances, making sure spare parts are available for a reasonable period after sale (e.g. ten years), and ensuring recyclability.

A sustainability template was proposed for manufacturers which would guide SMEs through what they need to do and encourages thinking about sustainability at the design stage. A template with default values for materials could be used to facilitate the process. However, it was pointed out that it could be difficult for companies to fully assess the sustainability of their products, as often materials are sourced from outside the EU and it can be difficult to obtain reliable information on their sustainability credentials.

4.2 Interviews with manufacturers, retailers/distributors, operators

4.2.1 Overview and objectives

Interviews were conducted with representatives from e-scooter manufacturers, retailers, distributors and shared micromobility operators. The objective of the interviews was to gather insights and views from these stakeholders on potential regulatory approaches, the rationale behind current e-scooter design and manufacturing processes, the extent to which current standards are followed and deemed appropriate and whether there are any particular concerns or perceived unintended consequences from future e-scooter regulation which stakeholders are keen to avoid.

4.2.2 General thoughts

These groups were generally keen to see regulation in place in the UK as soon as possible, with some citing the ability of other countries to implement legislation, for example Germany. While most did have opinions on what such legislation should contain, they were also of the opinion that clarity and certainty in itself was beneficial, even if it didn’t align specifically with their preferences. Some cited research suggesting that there was a large untapped market of potential e-scooter purchasers and users who were currently put off by the current lack of legislation. A general suggestion made by some was that e-scooters should be treated the same as e-bikes.

One observation was that the 'enforcement' part of the regulatory process should happen before the point of it being offered for sale in retailers or online. Further suggestions included keeping the regulations as simple as possible to allow minimum standards to be established and then allowing flexibility to innovate beyond those standards, and avoiding overregulation that could prevent some products from making it to market.

4.2.3 Regulations and standards

In the absence of any specific regulations and standards for e-scooters in the UK, manufacturers, operators and retailers referred to a wide range of related or more general standards which they typically aligned with. Primarily among them was EN17128:2020 which relates to test methods for personal light electric vehicles, and EN15194:2017, the EAPC standard. Others mentioned were a mixture of more general standards, and regulations or standards that have already been introduced in other countries, with Germany in particular and its ‘eKFV’ regulations cited as an example of good legislation. Automotive regulations covering areas that any existing e-scooter regulations do not cover were also mentioned.

Specific standards or regulations referenced in addition to those mentioned above included:

- UL2272 - Electrical safety
- UL2271 - Battery safety
- EC Directive 2002/24/EC

- ABE certified in Germany, via Dekra
- CE and UKCA approvals
- Regulations in Ireland (Road Traffic and Roads Act, 2023)
- VMP regulations in Spain
- GBT-42825 (2023) - new Chinese standard for e-scooters which includes a mix of elements similar to those in EN 17128:2020 and eKFV, along with a product level vibration test for evaluating battery safety

4.2.4 Training, education, licencing and registration

The issue of being able to identify and trace the owner of an e-scooter was discussed with some recommendations for number plates or a VIN number (e.g. as required in Spain).

One option discussed with regard to licencing was potentially operating a two-tier system similar to the current moped/motorbike and EPAC/L1eA systems, whereby perhaps low(er) power, low(er) speed e-scooters are made accessible to everyone (similar to EAPCs), but higher powered, higher speed e-scooters are only available to those with a licence and appropriate training and insurance (similar to L1eAs).

4.2.5 Power

Views on power limits saw some consensus, with most of those who discussed it keen to see limits of at least 500 W continuous rated power. A limit of 250 W was generally thought to not be enough, particularly in scenarios such as climbing a hill. One rationale cited for a limit of 500 W was that this would align with the current DfT guidance for the rental e-scooter trials.

There continues to be considerable confusion on the issue of how power should be measured and whether it is the peak or continuous measurement that is important from a safety perspective. This issue is discussed further in chapter 8.

4.2.6 Wheels

Wheels and tyres were another key theme, with bigger wheels (10 ” or larger) recommended for better stability and smoother starts, with one interviewee recommending in particular a large front wheel as this is key to stability, steering control and mitigating loss of control from pothole impacts. However, it was also noted that as wheel sizes increase, so does the weight of the e-scooter. In terms of number of wheels, while more wheels may have benefits for stability and safety, including allowing scooters to tilt, it was pointed out that it also increases complexity and there was scepticism from some stakeholders as to whether there was much of a market for scooters with 3 or more wheels.

4.2.7 Speed

Speed was another recurring theme, one thought included allowing speeds to match the speed limits on roads, as cyclists can do, but others suggested more specifically that 15 to 20 mph felt “about right” to enable safety and allow e-scooter riders to keep up with traffic. Some considered that 15.5 mph (25 km/h) is an ideal top speed for use in cities in the UK.

4.2.8 Stability

Stability was heavily discussed, with a wide range of variables suggested as critical for ensuring e-scooters maintain safe levels of stability – some of which were contradictory views presented by different stakeholders. These included:

- Having the footplate below the axle height of the wheels
- Using software to ensure smooth power delivery and avoid wheel spinning
- Allowing feet to be side by side rather than inline on the footplate
- Having a large front wheel and a smaller rear wheel
- Having a large wheel size generally
- Ensuring e-scooters have suspension (potentially with a minimum travel distance and wheel size)
- Embedding technical steering stabilisation solutions

4.2.9 Points of failure

While acknowledging that points of failure exist on e-scooters – particularly those at the cheaper end of the market - there was a general suggestion that scooter users should be educated on the sort of treatment e-scooters are able to withstand, as it was felt that a lot of users didn’t look after them and abused them beyond the design limits they were built to.

Areas identified as points of failure from a structural integrity perspective primarily centred around the handlebars and the handlebar stem, as well as the folding mechanism and associated locking pins. A specific recommendation was made for a minimum of two or three locking pins in order to provide redundancy in event of failures.

Outside of structural issues, electrical problems were also highlighted, particularly those stemming from a lack of water resistance allowing water ingress into control boards, with a recommendation that manufacturers should have to disclose IP ratings of their scooters.

The fire risks associated with e-scooters were attributed to unreliable suppliers and poor maintenance.

4.2.10 Tampering

Thoughts around tampering included that it should not be the responsibility of e-scooter manufacturers to police tampering, and it was felt that restricting the ability of individuals to be able to tamper with things like the motor would significantly reduce accessibility and therefore serviceability and sustainability.

4.2.11 Sustainability

Consideration was given to consumer buying patterns, with one thought being that they tended to buy cheap products first, then upgrade to more premium, better build quality products. It was posited that one of the issues with some imported models is that the models are not serviceable by the end consumer – in some cases parts are not stocked by some brands, particular those who produced devices at the cheaper end of the spectrum.

4.3 Accessibility workshop with disability charities

4.3.1 Overview and objectives

An online workshop was held with representatives from disability charities and other organisations focused on transport accessibility. The purpose of this workshop was to explore the risks and challenges that e-scooter use might pose for disabled people, gather ideas on technical solutions which might address those risks and challenges, discuss how technical regulations could be used to maximise the utility of e-scooters for disabled people, and discuss the potential opportunities and challenges that might arise for mobility scooters and powered wheelchairs through regulation of e-scooters.

4.3.2 Risks and challenges for disabled people by e-scooters

High speeds and rapid acceleration with e-scooters, particularly in shared spaces, and in comparison to e-bikes, were raised as key concerns for disabled people. Those who are blind or partially sighted were flagged as being particularly at risk, although the issue was identified as spreading further, for example the ability of those with restricted mobility to move out of the way of an e-scooter to avoid a collision. An example was shared that wheelchair users can’t quickly move sideways to get out of the way of an e-scooter. Negative impacts of the use of e-scooters on footways for disabled and non-disabled children (including those with learning disabilities or Special Educational Needs) were also raised. A maximum speed limit of 20 km/h was suggested, however speed on footways was seen as particularly important, and a ‘footway speed / walking speed’ setting (6 km/h as per mobility scooters) was also proposed It was felt this would be beneficial for other road or footway users and essential for users of e-scooters who are disabled. It was raised however that consideration would need to be given about when and where this could be used and how it would be implemented and enforced. Technical solutions were discussed in the form of geofencing/geolocation and computer vision which enable detection of when a e-scooter is on a footway to automatically limit the top speed; as is now common with some shared e-scooters.

Artificial noise or acoustic alerts were discussed as an important mitigation, with it being suggested that a standard universal acoustic alert is used across all operators and manufacturers to avoid confusion. It was identified that it would be useful if distance and direction of travel could be easily detected from the sound. Research into these areas by University College London and TIER was highlighted. It was further suggested that different acoustic alerts that would allow e-scooters to be distinguished from e-bikes may also be useful. Finally, there was also a desire for any artificially generated noise to be able to be switched off in some environments, e.g. if they are being used indoors.

Lighting was also deemed important to increase the visibility of e-scooters to those around them. Current e-scooter lights were considered as being too low to the ground, not at eye level, so potentially difficult to see. Research into lighting that shines upwards to illuminate the rider was mentioned, with potential safety benefits for both the e-scooter user and those in the vicinity.

In the event of an e-scooter colliding with a pedestrian, it was seen as critical to minimise injury, and participants were keen to understand how this could be addressed in the technical regulations. The mass of e-scooters in the event of a collision was identified as a key concern, with at least two organisations keen to see a maximum mass limit of 20 kg in order to minimise injury risk. Mass was further raised as an issue if e-scooters were left abandoned on the pavement and needed to be moved to allow someone to pass; an issue which has arisen with shared e-scooters in some areas.

A general point was made that you cannot regulate technical requirements with the intention of stopping inappropriate use – because the use of these devices is covered by other laws. Instead the technical regulations need to set out the absolute minimums for e.g. speed and power, and these things need to be enforced, through regulation, before the point of sale.

4.3.3 How can utility of e-scooters be maximised for disabled people?

A number of technical requirements which are essential if disabled people are to be able to use e-scooters were flagged. Key among these were having more than two wheels, seats, and the capacity to carry two or more people. Adjustability of features, e.g. for shorter people, was also considered as important. Where meeting these requirements might have a negative impact on mass and the implications for injury risk in the event of a collision, it was argued that impact and collision testing would be needed to explore ways of reducing injury risk.

This led to a discussion on how much it is necessary, or desirable, to differentiate between a mobility scooter and an e-scooter. It was suggested that the addition of a seat means that the device could come into the realm of the mobility scooter regulations. In addition, the collision profile and risk of injury is highly dependent on the centre of gravity and the shape of that vehicle, which would be affected by the addition of a seat.

Key questions then raised were:

- Why can something with a seat not just be a mobility scooter rather than an e-scooter?
- What can be done to differentiate them?

One reason raised for the differentiation was that anything that is used for a medical purpose (which includes mobility scooters currently) is classed as a medical device – whether or not it has been registered as such.

Some organisations raised that they felt strongly that they did not want there to be a separation or distinction between micromobility for disabled people and micromobility for non-disabled people as this was felt to be discriminatory, leading to higher costs and hugely limited vehicle choice for disabled users. In addition it was raised that there is something colloquially known as the ‘disability tax’ – where disabled people have to pay multiple times more for the basic things they need compared with non-disabled people at a time when there is very little funding for mobility aids.

This argument was further expanded on by highlighting the poor quality of mobility aids provided through the NHS, regional variation in what is provided, and very long waiting times – over a year in some cases. This was seen to create an environment of discrimination against disabled people who are trying to fulfil their basic mobility needs. The lack of funding available and the high cost of medical equipment for disabled people was seen as a key consideration in setting up the regulations to enable use of micromobility by disabled people. It is important that e-scooters are as inclusive and accessible as possible for disabled people to help combat these issues. 'Mobility justice' was seen as a key outcome – equal access to mobility and equal ease of use of mobility for everyone.

It was suggested that it is therefore important to consider the outcomes that accessibility organisations are looking for from regulation, which are essentially safety and access.

A recommendation was made that if a device is powered (in some way) and has wheels – then it could be classed as an 'e-scooter' – or more strictly, a micromobility device. Having a single category for all small, low-speed, lightweight mobility devices (including those specifically aimed at disabled people) was seen as a highly progressive approach which would vastly simplify things for all.

It was also highlighted that mobility scooters largely do not conform to the regulatory requirements placed on them today – including battery safety, power and quality – so including them within the scope of new technical regulations for e-scooters could in fact increase compliance and improve safety. E-bike regulations were seen as a good model for e-scooter regulations – speed and power form the basis of the regulations, and variations of the vehicle form factors (two, three, and four wheeled, cargo bikes etc.) are permitted. Safety critical areas that were flagged as key to define in regulations were structural integrity, water protection, and electrical safety. Other requirements which were considered desirable included being able to use the devices on the footway (at lower speeds) as well as the road, and it was raised as important to ensure that disabled people's use of e-scooters on footways is not punished as a result of the misuse of non-disabled people.

Concerns were raised about if there are going to be any requirements on skill level or licencing because this could be an additional burden given the system is seen by some as very punitive and discriminatory against disability; it was reported that there is considerable stigma associated with declaring yourself as disabled. A requirement to have a licence to use an e-scooter could also have implications for carers (e.g. it is common for a child to bring a wheelchair to their parent) – so it would be good if e-scooters could be usable by a broad spectrum of potential users. E-bikes are legal to use at age 14 – which was suggested as a good starting point for e-scooters. Registration of e-scooters was also discussed, with number plates or similar methods suggested to enable easy identification and support enforcement.

A general point was made that historically it has been very difficult to identify what standards apply to different types of device, and whether there is something that can be done to make this more transparent to support compliance and enforcement.

Finally, on a practical level, it was raised that for disabled users luggage capacity is important for shopping and the carriage of essential medical equipment, for example a stick, or oxygen supplies.

4.3.4 Implications for powered wheelchairs and mobility scooter users

Debate during this part of the workshop ended up focusing on battery accessibility, and being able to transport e-scooters on other transport modes. Being able to easily access and charge batteries was seen as important, particularly if batteries were big and heavy and needed to be removed for charging. A maximum mass for batteries was suggested, with multiple smaller batteries perhaps an option. The ban on the use of e-scooters on public transport (e.g. on the Transport for London network) was thought to have a disproportionate impact for disabled people, with particular implications for powered wheelchairs and e-assist mobility aid users. The Equality Act does require specific reasonable adjustments to be made to accommodate for disabled people on public transport and other modes of transport, – but in practice this doesn't always work out, with drivers, pilots, operators, etc reportedly taking an inconsistent approach. The Public Service Vehicles Accessibility Regulations (PSVAR) were referenced, but it was argued that they do not specifically state that e-micromobility should be allowed on public transport. Finally, as noted earlier – restrictions on the use of e-scooters on footways and inside buildings were seen as something that could be a huge disadvantage for disabled people.

4.4 Engagement with disabled people

4.4.1 Overview and objectives

A series of interviews were conducted with people with different disabilities and health conditions (detailed in Section 2.6). The purpose of these interviews was to gather insight into the potential demand for e-scooters among disabled people, along with their needs and challenges around personally using e-scooters as well as encountering e-scooters when travelling as another type of road user. Specific focus was given to the physical design of e-scooters across these topics in order to inform understanding of what factors are critical for ensuring future e-scooter technical requirements enable accessible e-scooter designs. Findings from these interviews are discussed in the sections below, with direct quotes from participants included in italics where they help to illustrate key themes.

4.4.2 Risks and challenges for disabled people by e-scooters

Across the interviews, it was observed that participants' views towards e-scooters could be loosely categorised into two opposing groups. The first were those that held broadly positive attitudes towards e-scooters, who were typically active e-scooter users or e-scooter owners, or those that were interested and have explored purchasing their own e-scooter. The second group were those who typically held strong negative attitudes towards e-scooters, often stemming from having had negative experiences of encountering e-scooters or from seeing them being used inappropriately. However, many of those in the latter group could still recognise benefits of e-scooters as a transport mode; for example, being able to commute across busy city environments without relying on public transport options. It is worth noting here that those who held more negative attitudes towards e-scooters outnumbered those with positive attitudes by roughly 3:1 (though this is an indicative estimate based on researcher judgement only).

Among those in the former group, it was reported that e-scooters allowed for an easy and enjoyable means of travel around city environments. In particular, it was said that they are “good for those with mobility issues to have a bit more independence”, especially for those where walking for extended periods can be painful because of health conditions such as fibromyalgia. Further, these individuals indicated that they did not foresee any significant risks associated with having e-scooters as part of the transport system. At the very least, it was felt that e-scooters posed no greater risk than existing transport modes: “They’re lightweight, and take up no greater space than cyclists, runners, dog-walkers”.

In comparison, it was among those with generally negative attitudes that many risks and challenges were raised around e-scooters. The most common example raised was inappropriate riding behaviour of some e-scooter riders. Participants raised examples of first-hand experiences of seeing “teens in black hoodies” and “kids” “zooming around on them” and “causing a nuisance”. One example that was mentioned on more than one occasion involved such riders emerging out from behind parked cars into roads without any warning. Participants explained that such experiences create an added level of stress when driving that they are put off from using their car to take certain journeys. This also applies to individuals encountering e-scooter riders on footpaths, with roughly a quarter of the sample reporting having, or knowing someone that has, been knocked over by an e-scooter rider, or being involved in a near-miss collision with one.

Another example that was raised on a few occasions was users of shared e-scooters “dumping” them on public footpaths and pavements when they are no longer in use. It is worth noting that this was felt to be a critical issue among participants who used mobility aids such as crutches and wheelchairs; however, one participant also raised that “if someone was blind, they wouldn't see them and you could easily trip over one”. One participant with cerebral palsy explained that they had felt at risk when navigating a pavement because they did not have the ability to move parked e-scooters out of the way due to walking with crutches. The same participant also had experiences of nearly being knocked over when using a pedestrian crossing as e-scooter riders on the road were choosing not to stop at the red light. This problem was felt to be made harder to avoid due to the quiet running of e-scooters making it difficult to know when e-scooters are approaching. Such examples of negative experiences were judged to be more a problem of inappropriate rider behaviour than e-scooter design, which creates and perpetuates a negative perception of e-scooters.

One risk that was raised by a few participants was that around battery safety. Specifically, these participants were familiar with reports of e-scooter (and similar devices) batteries catching fire. This hazard risk was a critical concern among some participants to the point that it significantly deterred them from ever considering owning an e-scooter; “I’d be reluctant to get one if only because of the fire hazard and the batteries”. This links back to the points around battery safety discussed in Section 3.2.2.3and later in Section 9 and demonstrates the impact that public reports on fire risk may have on the uptake of e-scooters. Negative perceptions around the fire risk associated with e-scooter batteries needs to be addressed through reducing the actual fire risk while improving public awareness of these issues. This would help in combatting any myths, misunderstandings and negative impacts on perceived safety and adoption.

The perception of e-scooters and their users appeared as a common influencing theme across the interviews. This links back to the point mentioned previously around some participants seeing e-scooters being misused by younger people. Particularly among the older participants, both seeing teenagers using e-scooters and the 'classic' e-scooter design being reminiscent of a child's kick scooter, act as a deterrent to use. E-scooters were described as being "more childish" when compared to the likes of a mobility scooter, which has the advantage of more clearly indicating to others that the user has mobility needs. Some of the older participants had concerns that they would "look silly" riding an e-scooter and this significantly disincentivised them from ever using one.

On the other hand, there were some participants who saw no appeal in using a mobility scooter over an e-scooter. These were typically active e-scooter users who felt that using a mobility scooter was "just too noticeable", as in it was felt to draw attention to them as being impaired. This relates to the point raised in Section 4.3.3around the recognised stigma associated with presenting oneself as disabled. An e-scooter instead allows them to have a greater amount of mobility and independence while being considered "more visually appealing" than a mobility scooter.

However, among these participants, it was also felt that the decision to use an e-scooter over a mobility scooter would ultimately depend on the degree of one's disability and needs, and it was felt that the current designs of e-scooter and mobility scooter are likely to suit different people's needs at different times. This shows that e-scooters were not judged to be suitable for all needs. Many participants showed a desire for more flexible designs that better accommodate a range of different needs. For example, participants often raised a desire for a device that sits between an e-scooter and a mobility scooter. This proposed device was loosely described as having some of the additional features of a mobility scooter – primarily a seat and greater stability – while having a less bulky and more lightweight body, more akin to that of an e-scooter. In essence, it would appear beneficial to be less restrictive in the design of e-scooters so as to enable features such as more than two wheels and seats.

4.4.3 How can utility of e-scooters be maximised for disabled people?

4.4.3.1 Design features

Interviewees suggested a number of design features which would either be necessary or advantageous for them to use, or consider using, an e-scooter safely and comfortably. The two most frequently suggested of these features were having the option to sit down and elements that improved device stability. Many individuals expressed having trouble balancing – which they felt would be exacerbated by the poor quality of the road and footway conditions in the UK – and they were thus concerned that they would not be able to operate an e-scooter safely. A greater number of wheels, having a wide enough platform on which to place one's feet side by side, and having a seat, were all suggested as features which would enable individuals to feel more confident operating the device; the former two elements helping to improve the stability of the device. Seats were also frequently cited as desirable on their own terms. For example, one individual said that they would be able to use an e-scooter "*only if there was a seat option, as I have mobility issues and can't walk on my own for long*".

Safety features common to other vehicles – such as lights and auditory signals – were also frequently mentioned as being desirable. It was recognised by individuals making these suggestions that they had a responsibility to consider other road users: "*it's more of a safety thing… so other road users can be made aware that an e-scooter is in the area*". This can be contrasted to the lack of consideration these individuals thought current e-scooter users have for others: "*there is a mentality of e-scooter users thinking they have a right of way*". Having the option to give an audible alert, such as that made by a bicycle bell or horn, was an important feature for users and potential users.

Making e-scooters more audible and more visible were also frequently mentioned design features which would improve disabled people's experiences with them as other road users. Many interviewees stated that they often struggle to hear e-scooters approaching when travelling as a pedestrian which, at the very least, can startle them when they pass: *"they're on the pavement a lot which is quite horrible because if they're silent… they just tend to whizz past you*". For those who can see or hear them in time, some mentioned difficulty in moving out of the way quickly due to mobility or balance issues: "*if I had to jump out of the way, I would struggle*". Anecdotes were shared of being or nearly being knocked over as a result: "*my daughter had to push me out the way and there was quite a big puddle and I fell in that*". Individuals therefore suggested a need to have some form of auditory signal which would alert them of their presence, similar to the points made by disability charities in Section 4.3. Similarly, one individual mentioned not being able to see adolescents who were using e-scooters in the middle of the road at night while she was driving. To make e-scooters more visible, it was frequently suggested that e-scooters could have lights added or be made brighter with the use of reflectors.

Other design features to improve accessibility were raised by some participants. Some highlighted the importance of e-scooters being lightweight, while another expressed the need or desire to have some form of storage option. Individuals who wished for a lightweight model said that they would have trouble lifting heavier models, whether that be into a car, upstairs, or onto a kerb. In addition, having more lightweight models of e-scooter may help pedestrians when they need to move stranded shared e-scooters out of the footway (though this would not be considered a solution to this problem). While e-scooters were seen as modes of transport which could enable independence, having models which cannot be moved easily would be a barrier to using them, as they may restrict the amount of independence that can be gained. For those wishing to use e-scooters to do their shopping, having a basket or some form of storage capability was necessary. One individual was concerned that having to carry bags on the handlebars would make the e-scooter unstable and unsafe.

Several other features were raised as desirable but only by one or two individuals in the group. These included: having greater control over speed through the use of different speed modes or settings, mirrors, indicators, automatic braking/collision technology, more protection for the rider, an emergency button, the ability to transport multiple people, kickstand, anti-theft technology, foldability, phone holder, good battery range, and waterproofing. As well as having designs with different features available for purchase, individuals suggested a basic model or design with the option to purchase modular add-ons such as baskets, seats, or lights could be useful.

Having sufficient flexibility in the basic structural constitution of the e-scooter was also raised as important. As put by one individual, "*one fit doesn't fit all*", and thus adaptability to the needs of a user is imperative to mitigate individual pain points. In the same way that a bicycle saddle can be raised or lowered to fit the height of its user, a standard e-scooter design or build size would not be appropriate for all users; having the option to adjust features such as the height of the handlebars (etc) ensures a more comfortable, and ultimately safer, ride.

Ultimately, it is clear from the interviews with disabled people that there is a broad array of features perceived to be either necessary or desirable, thus indicating that from the perspective of defining technical requirements for e-scooters it is critical for accessibility to have a sufficiently open and flexible set of requirements which enables the market to respond to different demands. In contrast, having a set of technical requirements which mandates or restricts the inclusion of certain design requirements would be likely to greatly hinder the accessibility and potential uptake of e-scooters among disabled people.

4.4.3.2 Non-design related measures

In addition to physical design features of e-scooters, individuals discussed several more general suggestions to improve their experience of and with e-scooters if they were legalised for use in public spaces. There was unanimity among participants that the risks presented by e-scooters were caused by improper rider behaviour, rather than by the specific design of the machines themselves: "*accidents could be avoided by having lights, but that doesn't mean the rider is going to ride it any safer*".

To mitigate such behaviour, and thus the risks to themselves, individuals felt that regulations surrounding their use needs to be stricter, and that enforcement of the regulations needs to be stronger than is currently perceived to be the case. It was commonly stated that e-scooter users should be required to show a valid driver's licence before purchasing a device and have the device registered. Registering devices, leading to them having some form of identification plate, was felt important for identification purposes in the event of needing to report improper behaviour. A lack of appropriate infrastructure was often mentioned as leading to e-scooter riders creating more risk for other road users, whether that be to pedestrians when riding on the footway or to motorised traffic when weaving in and out of congestion. Another common suggestion was therefore that e-scooters should have their own area of operation, segregated from other road users.

4.5 Final stakeholder review workshops

Towards the end of the project, stakeholders were invited to participate in one of three final stakeholder consultation workshops. The workshops brought together stakeholders who had previously engaged in this project, including manufacturers, operators, disability charities and road safety organisations. The purpose of the workshops was to share the key findings and draft recommendations on e-scooter technical requirements and gather additional feedback from stakeholders so this could be considered prior to production of this final report.

The workshops were held online with numbers limited to a maximum of 20 people per workshop in order to encourage discussion, and filled on a first-come first-served basis. All three sessions followed the same format, with TRL and WMG sharing findings and draft recommendations for each key area, and then seeking feedback from stakeholders. Across the three workshops, 29 stakeholders attended, all representing a different organisation or company.

This section presents a synthesis of the feedback received across the three workshops, grouped by topic.

4.5.1 Sustainability, environmental impact and lifecycle

We raised the following topics for discussion:

- “Right to repair” regulations should be established for e-scooters.
- The mandatory warranty period for e-scooters should be extended to at least two years.
- Feedback from stakeholders included:
- The durability of rental e-scooters isn’t matched by private scooters, but the characteristics of rental e-scooters (e.g. mass) aren’t seen as desirable by private purchasers.
- It is a challenge to work out lifecycle emissions for e-scooter components, and expensive to do so.
- Agreement that e-scooters shouldn’t be throwaway products; mandatory two year warranties was seen to help prevent this.
- Not all e-scooter manufacturers provide warranties or spare parts currently, and as such it often falls to the retailer to provide the warranty at their expense. A long warranty could potentially be a considerable financial burden on a retailer.
- The role of consumer rights laws and trading standards should be considered in relation to poor quality or faulty products.
- It was thought by some that these requirements would not make any difference to ‘unofficial’ sellers on platforms like Facebook who pop up and sell scooters and vanish again, without providing any longer term customer service or support.

4.5.2 Battery safety

We suggested:

- EN 17128:2020 should be updated to have the same requirement as EN 15194:2017 regarding the battery, and therefore the battery must comply with EN 50604-1:2016+A1:2021.
- EN 50604-1 should be applied to the batteries of e-scooters.
- EN 50604-1 should undergo a thorough revision.

Stakeholder feedback included:

- Agreement that updates should be made to EN 50604-1 to address current shortcomings.
- Some of the requirements in EN 50604-1 are difficult to meet because they are made for a wide range of light electric vehicles, not just e-scooters.
- Fires are often due to modified elements of e-scooters or e-scooters bought online.
- When the correct battery is plugged into the correct charger incidents are become “vanishingly low”.
- Reputable e-scooter brands usually meet US standards around battery safety which were considered tougher than EU standards currently.
- It was thought by some stakeholders that issues around battery safety were having more of an effect on sales than uncertainty around future regulation.
- It was felt that if government doesn’t regulate battery safety, the insurance industry will.

4.5.3 Hill climb ability and vehicle power

We recommended:

- Limiting acceleration rather than power.
- Implementing an acceleration limit of 2 m/s^2.

Stakeholder feedback included:

- A mixed view on whether or not acceleration should be limited.
- Cars and motorbikes can exceed most regulations, but are still allowed on the road.
- Irresponsible acceleration should be an enforcement issue not a regulation issue.
- Queries over how the maximum acceleration rate would be implemented, and how it could be done in a way that would prevent tampering.
- Some stakeholders were not sure acceleration was a big problem, instead mass and the top speed were considered the primary defining factors in a collision.
- E-scooters could start up in a ‘comfort mode’ with a limitation of around $2m/s^2$ or so initially.
- The current 250 W limit has no technical or scientific background and is preventing the development of the e-scooter market.
- Motorcycles are currently categorised and type-approved based on power, whereas the recommendations to focus on an acceleration limit instead would move away from that.
- Both peak power and continuous power should be considered.

4.5.4 *Vehicle configuration and integration with vehicles for disabled people*

We suggested that:

- E-scooters should be allowed to be fitted with (and without) seats, and have 2, 3, 4 or more wheels.

Stakeholders said:

- The ‘invalid carriage’ regulations were old and inadequate.
- The category of ‘invalid carriage’ limits the ways in which disabled people are allowed to move around.
- The Road Traffic Act is under review and that can also be used to address some of these areas.
- E-scooters have become very important for people with limited or restricted mobility, but who don’t require a mobility scooter.

4.5.5 *Maximum mass*

We recommended:

- Regulating the laden mass of the machine.

Stakeholders said:

- Most people aren’t 150 kg - allowing e-scooters to have a total laden mass of up to 200 kg could lead to production of heavy e-scooters.
- Some countries have limited e-scooter mass to 25 kg.
- Mass is a key factor for the level of risk posed to vulnerable road users.

4.5.6 *Maximum speed*

We raised the following topics for discussion:

- Mandating that e-scooters include a system to limit the maximum speed.
- Allowing the use of e-scooters on the footway at 4 mph in order to maximise their accessibility to disabled users.
- Placing onus on manufacturers to take reasonable precautions to ensure that speed limitation systems cannot be easily defeated.

Stakeholders said:

- A speed limit above 15.5 mph may lead to a modal shift away from walking.
- Pedal cycles can go faster than 15.5 mph.
- Speed differentials may be an issue, both in relation to cars, and to pedestrians and pedal cyclists.
- Mobility scooters can already be limited to 4 mph on the pavement, so this should be achievable for e-scooters.
- A 4 mph limit for footway use would reduce the risk both to pedestrians and to the e-scooter rider.

4.5.7 Structural Integrity

We recommended:

- Revision of BS EN 17128:2020 to incorporate more robust requirements for both structural overload and fatigue.

Stakeholder feedback included:

- Agreement that BS EN 17128:2020 structural integrity requirements are inadequate.
- Complying with a stronger standard could be a selling point for manufacturers.
- A basic structural integrity level and standard impact test is needed to ensure e-scooters can cope with heavier individuals riding them.
- A basic integrity requirement and a warranty requirement could be a possible approach going forward.
- Some felt that e-scooters might need to move to a type-approval process rather than complying with the Machinery Directive.
- TC125 for e-transporters, the German type-approval system for e-scooters, and the Dutch LEV framework were cited as useful sources to inform the UK’s approach.

5 Regulatory landscape for low speed zero emission vehicles

The DfT has proposed to create a Light Zero Emission Vehicle (LZEV) category within the Road Traffic Act. This category would include within it sub-categories for different groups of light vehicles, of which e-scooters would be one, and these vehicles would effectively sit outside the remit of motor vehicle regulations (i.e. the L-category). Currently however e-scooters have no formal definition, and the DfT are considering the possibility that the e-scooter subcategory might include machines with 2, 3 or 4 wheels, with or without a seat, ridden by a single rider, steered using handlebars. This definition would create some overlap with the L-category which would require an amendment to existing regulations. This new LZEV category would also be functionally adjacent to the existing 'Invalid Carriage' regulations for machines specifically designed for use by disabled people.

5.1 L-category regulations

UK law currently incorporates assimilated Regulation (EU) No 168/2013 which sets out the technical regulations for light, powered vehicles including mopeds, motorcycles, powered tricycles and quadricycles – collectively referred to as the L-category. The L-category is subdivided into seven sub-categories L1 – L7 mainly according to the number of wheels a vehicle has, and its mass, engine power or size, and maximum speed. Regulation (EU) No 168/2013 specifically excludes:

- Machines intended primarily for use off road,
- Machines with a top speed of 6 km/h or less,
- Electrically assisted pedal cycles (EAPCs) which have a maximum continuous rated motor power of 250 W or less and a maximum motor assisted speed of 15.5 mph (25 km/h),
- Self-balancing machines e.g. hover-boards,
- Machines with only one wheel,
- Machines designed specifically for the use of disabled people,
- Machines without seats, and machines with seats lower than 540 mm, or 400 mm depending on category, above the ground.

Thus e-scooters in which the rider stands on a footplate are excluded from the L-category, while those that have a seat, in theory at least, fall within its scope. In practice almost all e-scooters currently available on the market are not compliant with the technical requirements set out in Regulation (EU) No 168/2013, and none have achieved type approval. A small number of machines have successfully completed the Motorcycle Single Vehicle Approval (MSVA) process and been granted registration.

5.1.1 E-scooter market review

A high-level review was undertaken to establish the range and availability of scooters with more than two wheels, and scooters with a seat. In both instances, a limited number of models were identified as being sold in the UK by UK based retailers. The tables below present those found after a rigorous, but not exhaustive market review. It is possible that others may be available, but if so we suggest they are not easily identifiable.

E-scooters with seats appear to fall into two categories, those where the seat is mounted on the top of a pole, usually affixed to the footboard, and those where the seat or seat pole is integrated into the frame of the e-scooter. For e-scooters with three wheels, the main differences were whether the pair of wheels was at the front or rear of the e-scooter. Only one e-scooter was identified with four wheels. One e-scooter, the Coolfly CF-T11-3, featured three wheels, and an optional seat.

Table 4: E-scooters available with seats

No.	Make	Model	Post or frame seat	Top Speed (mph)	Empty Mass (kg)	Max rider mass (kg)	Length (mm)	Width (mm)	Height (mm)	Motor Power (W)	No. of wheels
1	iScooter	iX5 800W Off Road E-Scooter	Post	28	27.29	150	1180	600	1230	800	2
2	Zipper	Electric Scooter 800W	Post	15.5	40	120				800	2
3	Zipper	M6	Frame		23	120				350	2
4	Windgoo	B9	Frame	15.5	24.2	120	1200	535	990	250	2
5	Hitway	H5	Post	28	27	200	1190	280	470	800	2
6	Engwe	S6	Post	15.5	26	120	1160	250	1060	500	2
7	CoolFly	CF-T11-3	Post	43	53	150	1300	560	1280	5400	3

Table 5: E-scooters available with three or four wheels

No.	Make	Model	No. of wheels	Layout	Top Speed (mph)	Empty Mass (kg)	Max rider mass (kg)	Length (mm)	Width (mm)	Height (mm)	Motor Power (W)
1	Future	10	3	Two at rear	21.7	17	100	820	450	1100	500
2	8TEV	C12 Roam	3	Two at front	21.7	19	120				250
3	Yawboard	All-Terrain	4	2x2	21.7	13.75	100				1500
4	CoolFly	CF-T11-3	3	Two at rear	43	53	150	1300	560	1280	5400
5	CityBot	City Board	3	Two at front	22	21.7	110	1045	465	1170	450

5.2 Mobility scooter regulations

Statutory Instrument 1988 No.2268 “The Use of Invalid Carriages on Highways Regulations 1988” sets out three classes of ‘invalid carriage’ (referred to here on as ‘mobility scooters’ except where direct quotes are provided):

- Class 1 – not mechanically propelled (wheelchairs)
- Class 2 – mechanically propelled with a maximum speed on the level under its own power of 4 mph
- Class 3 - mechanically propelled with a maximum speed on the level under its own power of more than 4 mph but not more than 8 mph

The statutory instrument restricts the use of mobility scooters to people with a physical disability and prohibits the use of Class 3 devices by those younger than 14 years old.

The statutory instrument sets out the acceptable technical characteristics of each class of mobility scooter (Table 6).

Table 6: Technical and usage requirements for mobility scooters

Requirements	Class 1	Class 2	Class 3
Maximum unladen mass	113.4 kg (or 200 kg if necessary user equipment is fitted)	113.4 kg (or 200 kg if necessary user equipment is fitted)	150 kg (or 200 kg if necessary user equipment is fitted)
Maximum speed	Unspecified	4 mph	4 mph when used on the footway 8 mph when used on the road
Service braking	Unspecified	“…shall be capable of being brought to rest in all conditions of use with reasonable directional stability and within a reasonable distance.”	Same as Class 2
Parking brake	Unspecified	“When the invalid carriage is not being propelled or is left unattended it shall be capable of being held stationary indefinitely in all conditions of use on a gradient of at least 1 in 5.”	Same as Class 2
User activated speed limiter	Unspecified	Unspecified	Must be fitted with a device which the user can activate to limit maximum speed to 4 mph
Speed indicator	Unspecified	Unspecified	Must be fitted

Requirements	Class 1	Class 2	Class 3
Maximum width	Unspecified	Unspecified	0.85 m
Horn	Unspecified	Unspecified	Must be fitted
Rear view mirrors	Unspecified	Unspecified	Must be fitted
Lighting	Unspecified	When on the road must comply with the Road Vehicle Lighting Regulations 1984	Same as Class 2
Areas of permitted use	Footpaths, pavements, bridleways and in pedestrian areas	Same as Class 1	Same as Class 1
Permitted road use	Where pavements are not available and to cross the road	Same as Class 1	Most roads except motorways, bus lanes and ‘cycle only’ cycle lanes
Permitted user groups	Unspecified	Only disabled people	Same as Class 2
Age limit for drivers	Unspecified	Minimum 14 years	Same as Class 2
Driving licence	Not required	Not required	Not required
DVLA registration	Not required	Not required	Required
Road tax and insurance	Not required	Not required	Not required

5.2.1 *Mobility scooter market review*

We undertook a market review to explore the range and diversity of the mobility scooter market and its overlap with the e-scooter market. Through this review we identified 26 examples of mobility scooters from manufacturer websites, retail outlets and e-commerce platforms (see Table 7The review was not exhaustive but intended to identify example models of mobility scooter which illustrate the broad spectrum of devices available for purchase in the UK. In the table below we summarise key information for each model with regard to speed, dimensions, motor power, weight capacity, vehicle class and number of wheels.

The key findings from this review are as follows:

1. The reported top speed of mobility scooters ranged from 3 mph to 9.3 mph. The one machine found with a claimed maximum speed greater than 8 mph exceeds the limit set for Class 3 ‘invalid carriages’, but anecdotal reports suggest that many mobility scooters have top speeds greatly in excess of the limit.
2. The motor power of the sampled models varied from 180 W to 3,000 W; 50 % of the sample had a motor power of 800 W or more (based on 19 mobility scooters as no information on power could be found for 7 of the models).
3. The unladen mass of the mobility scooters ranged from 5.7 kg to 165 kg.
4. The maximum rider mass ranged from 95 kg to 180 kg.
5. The dimensions varied considerably in terms of length, width and height

6. Two, three and four wheeled variants were identified. Both of the two wheeled variants identified are self-balancing with the wheels sharing a common axis rather than being one behind the other like an e-scooter.

Table 7: Mobility scooter market review (assembled from publicly available information - not all parameters were available for all machines)

No.	Make	Model	Top Speed (mph)	Empty Mass (kg)	Max rider mass (kg)	Length (mm)	Width (mm)	Height (mm)	Motor Power (W)	No. of wheels	Vehicle Class
1	Genny	Genny Urban 2.0	7.4		95	700	690		3000	2	3
2	Genny	Genny Zero	9.3		110				2000	2	3
3	CareCo	CareCo Fronteir	4	41.7	114	1041.4	482.6	838.2	180	4	2
4	TGA Minimo	TGA Minimo Plus 4 (2019)	4	30	114	939.8	508			4	2
5	Minimus	Minimus Folding Mobility Scooter	4	17.8	114.8	925	425	750		4	2
6	Drive DeVilbiss	Wheelchair Power Assist Inc Reverse Dual Wheel Attachment	3	14	115				100		2
7	Livewell	Livewell Discovery Plus Auto Folding Mobility Scooter	4	22	115	890	620	860		4	2
8	illman	Hillman Lithium Mobility Scooter	5	56	120	1092.2	1270	2413	250	4	3
9	Lithlite	Lithlite Pro Portable Travel Mobility Scooter	4	41	133	900	500	1050	200	4	2
10	X-Go	X-Go Cosmic	4	48	135.6	1030	560	910	180	4	2
11	Rascal	Rascal 388 All-Terrain Electric Mobility Scooter	6		136	1250	540		180	4	3
12	SmartDrive	MX2+ Wheelchair Power Attachment	4	5.7	150				250		NA
13	Sterling	Sterling S425 (2023)	8	108	150.5	1346.2	660.4	1257.3		4	3
14	Invacare Orion	Invacare Orion Pro 4W (2021)	8	126	158.8	1320.8	660.4	1244.6		4	3

No.	Make	Model	Top Speed (mph)	Empty Mass (kg)	Max rider mass (kg)	Length (mm)	Width (mm)	Height (mm)	Motor Power (W)	No. of wheels	Vehicle Class
15	Pride	Ranger	8	165	159	1556	829		1800	4	3
16	Drive	Drive Royale 4 Sport Scooter	8		160	1690	750	1730	1500	4	3
17	Veleco	Veleco Faster	8	126	160	1600	700	1200	1000	4	
18	Veleco	Veleco Mobility Scooter Electric Mobile - Senior Model Car Electric Tricycle	8	93	160	1700	700	1300	900	3	3
19	Drive	Drive Devilbiss Viper Mobility Scooter	8	121	160	1430	660	1320	800	4	3
20	Envoy	Drive Envoy 4 Mobility Scooter	4	94	160	1210	460	1020	350	4	2
21	Galaxy	Galaxy Roadmaster Plus 4 (2021)	8	140	171.5	1460.5	711.2	1320.8		4	3
22	Green Power	Black ZT500 Electric Mobility Scooter 3 Wheeled	8	105	178	1651	688	1320.8	900	3	3
23	Drive	Driver Sport Rider Mobility Scooter	8	149	180	1650	780	1120	1300	3	3
24	Green Power	Unique 500 Road Range Mobility Scooter	8	105	180	1767.8	698.5	1250	500	3	3
25	Zipper	Folding 3 Wheel Electric Mobility Scooter	4	42		1100	260	1190	350	3	2
26	Shoprider	Shoprider Sovereign 4 (2021)	4	82		1257.3	584.2	965.2			2

5.3 Potential consequences of an overlap between mobility scooter and e-scooter technical regulations

We considered the possible advantages and disadvantages of an overlap in the technical regulations and functional characteristics of mobility scooters and e-scooters. It is entirely conceivable that manufacturers might choose to produce e-scooters with a seat and three or four wheels which superficially at least would be indistinguishable from Class 2 or 3 mobility scooters. Conversely it is also conceivable that manufacturers of mobility scooters might seek a broader market for their products by selling them as seated e-scooters. Indeed, there is anecdotal evidence from the EU that this is already happening in some EU member states. This blurring of the boundaries between adjacent but separate categories of machine has the potential to cause some unintended consequences for legitimate users of mobility scooters.

5.3.1 Medical device requirements

Mobility scooters are regulated as medical devices by the Medicines and Healthcare products Regulatory Agency (MHRA) under the UK Medical Devices Regulations 2002. The compliance process for medical devices is significantly more involved than even the type-approval process for motor vehicles. The medical device approval process however does not concern itself with the functionality of mobility scooters as vehicles, but instead is concerned with the way in which the user might interact with the device as an aid to their mobility. The range of users who might choose to use a mobility scooter is obviously very wide, with some having complex medical needs for which great care in design and approval is required to ensure that their interaction with the mobility aid does not cause injury or exacerbate their existing condition. The implication here is that simply removing the requirements of the UK Medical Devices Regulations 2002 for all mobility scooters is unlikely to be appropriate for all user groups. However, there is likely to be a significant number of users of mobility scooters, who are perhaps in better health, for whom the provisions of the regulation are not necessary to ensure their safe use of the machine, but who are still in effect paying for an approval process from which they derive little benefit. Conversely of course those costs, spread across a larger customer base, are reduced for those for whom the regulations are most relevant.

If e-scooter regulations were drafted in such a way that current mobility scooter users could instead use e-scooters, then we might expect to see a narrowing of the mobility scooter market, with an even greater specialisation towards devices aimed at the most vulnerable users. This however is likely to further increase the cost for those users who for whatever reason choose to use a mobility scooter rather than an equivalent e-scooter.

5.3.2 Tax implications

Class 1 and 2 mobility scooters are zero rated for the purposes of Value Added Tax (VAT). Class 3 devices can be zero rated provided they are “designed solely” for use by disabled people. The HMRC provides some guidance on how to judge whether a mobility scooter is designed solely for use by disabled people and is thus exempt from VAT. However, this guidance rests on subjective judgements of the ways in which a manufacturer intends its products to be used rather than objective technical characteristics. Thus, two identical machines could be judged differently purely on the basis of the way in which their respective marketing efforts were targeted. This has the potential to be particularly challenging for manufacturers with product lines that span across both mobility scooter and e-scooter markets, with the implication that legitimate users of mobility scooters might be financially disadvantaged by having to pay VAT on a device which might otherwise be exempt. But also the opportunity cost that the technological advances brought about by mass market potential in the e-scooter industry is slow to diffuse into a mobility scooter industry fearful of prosecution if its products become too similar to those intended for the e-scooter market.

5.3.3 Inappropriate enforcement and public attitudes

Currently the public and police are used to seeing mobility scooters operated on the footways, indoors and in other public places, and for the most part their presence does not result in conflict with other public space users or the police. It is reasonably foreseeable that an increase in the numbers of three and four wheeled, seated e-scooters, could lead to confusion around the restrictions and requirements for the operation of differently regulated but physically very similar machines leading to inappropriate intervention by the police and conflict with other public space users. This effect may be especially pronounced for younger users of mobility scooters. Consideration should be given to the necessity of providing some means of readily differentiating between mobility scooters and e-scooters, although this analysis should also seek to evaluate whether such a means of differentiation might have unintended negative consequences such as the stigmatisation of potential mobility scooter users who might welcome the opportunity to exercise their rights under the ‘Invalid Carriage’ regulations without the need to publicise their disability.

5.4 Potential consequences of an overlap between L-category vehicle and e-scooter technical regulations

The use of L-category vehicles is subject to a variety of requirements and restrictions including mandatory registration with the DVLA, mandatory licensing, insurance, road tax and periodic technical inspection (MOT), and for two wheeled vehicles, mandatory head protection. The design and manufacture of L-category vehicles is subject to formal approval either individually via the Motorcycle Single Vehicle Approval (MSVA) route or collectively, for a design of which multiple instances will be manufactured, under ‘type approval’ requirements. In creating an LZEV category, and an e-scooter sub-category within it, consideration must be given to where the new division between the L and LZEV categories will lie and which of these requirements from the L-category, if any, will be applied to the new LZEV category.

The current system draws a sharp distinction between ‘motorised’ and ‘human powered’ machines, with the former subject to strict regulation while the latter is subject to far fewer restrictions. Historically this distinction was based on the notion that powered vehicles were heavier and capable of higher maximum speeds and thus posed a significantly greater risk of injury than human powered machines. EAPCs have been allowed to occupy the legal intersection between human and mechanically powered machines because of their physical similarity, and comparable safety risk, to conventional pedal cycles. This assumption has been borne out by multiple studies which have shown that the safety risk associated with EAPCs is very similar to conventional pedal cycles. However, the introduction of EAPCs on a large scale has demonstrated that the safety risks associated with a particular transport mode are not only a function of the technical characteristics of that mode. For example, Vlakveld (2016) demonstrated that EAPCs have attracted a considerable number of older people to take up or resume cycling. These older cyclists tend to be more prone to accidents, particularly while mounting and dismounting, and are more easily and severely injured than their younger counterparts.

The L1e-A sub-category provides a useful cautionary tale about the ways in which well-meaning but poorly conceived regulation can fail. The L1e-A sub-category is for powered pedal cycles with two, three or four wheels with a maximum motor assisted speed of 25 km/h and a maximum continuous rated motor power of 1,000 W. While at first sight this sub-category seems like a useful home to the type of more powerful cargo bikes that are common in the USA, in the EU and UK the sub-category has failed to attract many manufacturers. The reason for this failure, while EAPCs have proved extremely popular, seems to be that potential users are put off by the additional restrictions and requirements that accompany inclusion in the L-category, while manufacturers have been put off by the significant additional cost of type-approval compared to self-certification. This situation has been compounded by the fact that while the allowable motor power in L1e-A is much greater than the 250 W allowed under EAPC regulations, the maximum speed is still capped at 25 km/h and thus functionally potential owners perceive no benefit.

6 Structural integrity requirements

We were made aware by the DfT, and our own review of media reports, of a number of structural failures that have affected e-scooters operated as part of the current shared e-scooter trials program. These failures typically affect the steerer tube at its lower end, at or close to the point where the steerer tube and fork assembly join. These failures often result in the complete detachment of the steerer tube and handlebar assembly from the machine with obvious significant risk to the safety of the rider. These failures are concerning as some at least have occurred in machines that were ostensibly compliant with the structural integrity requirements of BS EN 17128:2020. While the use case for shared e-scooters tends to be much more arduous than that of privately owned machines the catastrophic nature of these failures and the lack of warning that preceded them calls into question the robustness of the structural integrity requirements in BS EN 17128:2020 and safety of machines complying with them.

The current common design of e-scooters (e.g. Figure 1), with their low, flat frame and long, single tube steering assembly creates very high stresses at the joint between the frame and steering assembly. This area is often further weakened by the inclusion of a folding mechanism that allows the steering assembly to be folded flat against the footplate for storage. Since the rider is required to stand on the footplate they are heavily reliant on the steering assembly to keep their balance, and react loads created by sudden acceleration or deceleration e.g. hitting a kerb or pothole, the integrity of this structure is both critical to the safety of the machine and potentially very heavily loaded in use. The front forks of most e-scooters tend to be quite short and are thus much less susceptible to failure. Bicycles on the other hand commonly employ a design with a short steerer tube which is well supported in a deep frame structure. Bicycle riders tend to be much more closely coupled to the machine through the saddle and pedals and are thus less reliant on the steering assembly to react longitudinal forces, although these are still significant. Bicycle front forks tend to be longer than e-scooter front forks and are thus more highly stressed, but this is to some extent balanced by the larger wheels commonly fitted to bicycles, which make them much less sensitive to obstacles like potholes and kerbs, which in e-scooters can cause very high decelerations and thus longitudinal forces.

Figure 1: Example of an e-scooter offered for sale in the UK, with a long single tube steering assembly and low frame

Some manufacturers of e-scooters have chosen to apply BS EN 15194:2017, which is the harmonised standard for EPACs, to their products rather than use BS EN 17128:2020 which is the standard dedicated to personal light electric vehicles including e-scooters. In this chapter we have compared the structural integrity tests and requirements set out in these standards with the intention of making a judgement on the suitability of either standard for e-scooters offered for sale in the U.K.

6.1 Common areas of focus

The two standards have four common areas of focus:

- **Steering mechanisms**: The emphasis on handlebar and steering components in both standards underlines the critical nature of manoeuvrability and control in ensuring rider safety.
- **Frame**: Both standards emphasise the frame’s integrity, acknowledging its critical role in overall vehicle safety and durability.
- **Fork assessment**: The inclusion of frontal impact assessments in both standards signifies a common concern for structural integrity when the machine encounters obstacles like kerbs or potholes which cause sudden deceleration, which is vital for protecting the rider.

- **Fully assembled vehicle**: Each standard includes an examination of the vehicle as a whole, ensuring that all components work together effectively and safely.

Table 8 provides an overview of the structural integrity tests required by BS EN 17128:2020 and BS EN 15194:2017 for e-scooters and EAPCs respectively, while Table 9 and Table 10 provide an overview of the fatigue tests required by BS EN 17128:2020 and BS EN 15194:2017 respectively. While the principles and acceptance criteria applied under both standards are similar, it is apparent that BS EN 15194:2017 is much more rigorous in both its scope and requirements. This is perhaps most pronounced in the fatigue testing required by the standards, with BS EN 17128:2020 requiring only a single test of 20,833 cycles with a load of approximately 1,924 N while BS EN 15194:2017 requires three separate tests of the frame, a two-stage test of the handlebars and stem assembly and two separate tests of the front forks and front brake mount. While some of the tests in BS EN 15194:2017 are specific to the load cases encountered by pedal cycles, i.e. the cyclical loading produced by pedalling, most of the tests seek to replicate the load cases produced by riding across the types of obstacles encountered in daily riding on the road, e.g. potholes, drain covers, etc. which are common to both EAPCs and e-scooters. It should also be borne in mind that the speeds of e-scooters and EAPCs are intended to be similar, but the latter tend to have larger wheels and often more effective suspension which results in the actual road loads experienced by EAPC components being lower than those affecting e-scooters.

The structural integrity tests prescribed in the standards are almost invariably more robust in BS EN 15194:2017 than in BS EN 17128:2020. In some cases this may be justified by design differences between e-scooters and EAPCs, e.g. requiring a higher torque resistance in the steering assembly of an EAPC seems reasonable given that the vast majority will have larger wheels than those found on e-scooters and will thus be more likely to encounter higher steering forces, for example when the front wheel is trapped against a kerb. However, requiring a much lower static longitudinal or vertical strength for the steering assembly of an e-scooter compared to that of an EAPC seems much less prudent given the inherent weakness of the prevalent e-scooter concept discussed at the start of this chapter.

Given the in-service failures discussed earlier and the apparent leniency of the requirements of BS EN 17128:2020 it would seem prudent to consider the possibility of developing a revised standard for e-scooters. Feedback from manufacturers, particularly those who do not have a background in vehicle manufacturing, suggests that the existence of BS EN 17128:2020 is leading some to produce e-scooters which fail in service in a dangerous manner, as they are following its structural integrity requirements without the knowledge necessary to identify its shortcomings. The standard therefore is potentially making e-scooters less safe than they would be if it had not been published in the first place. It might therefore be tempting to adopt BS EN 15194:2017 wholesale as the standard for all electrically propelled light vehicles. But it must be borne in mind that there are significant differences in the design concepts and load cases of EAPCs compared to e-scooters. However, as a stop gap measure, adopting the most relevant structural integrity and fatigue requirements from BS EN 15194:2017 and applying them to e-scooters would be prudent.

Table 8: Structural integrity tests required by BS EN 17128:2020 and BS EN 15194:2017

E-scooter Tested part	E-scooter Load	E-scooter Type of test	E-scooter Test summary	E-scooter Requirement	EAPC Tested part	EAPC Type of test	EAPC Load	EAPC Test summary	EAPC Requirement
Frame	100 kg or 2.5x maximum permissible payload	Static load test	Static load applied to footplate for 1 minute. Test performed in cold conditions if components are plastic						
Frame and steering assembly	70 kg (50 kg on footplate, 20 kg on handlebars) Dropped from 200 mm Repeated twice	Impact test	Weighted frame dropped onto front wheel to simulate dropping from a wheelie onto the front wheel	No visible cracks or fractures, locking mechanism to remain locked	Frame	Impact test	90 kg (30 kg seatpost, 10 kg steering head, 50 kg bottom bracket) Dropped from 300 mm	Weighted bicycle frame dropped onto front fork to simulate dropping from a wheelie onto the front wheel	No visible cracks or permanent deformation of the wheelbase greater than 60 mm
					Front fork	Impact test	22.5 kg dropped from 360 mm	Mass dropped to simulate longitudinal impact on front fork	No visible cracks or permanent deformation greater than 30 mm

E-scooter Tested part	E-scooter Load	E-scooter Type of test	E-scooter Test summary	E-scooter Requirement	EAPC Tested part	EAPC Type of test	EAPC Load	EAPC Test summary	EAPC Requirement
Handlebar and steering column	50 kg (490.5 N)	Static load test (longitudinal)	Static load applied to the centre of the handlebars for 1 minute in, separately, the forward and backward directions	No cracks, fractures or deterioration of the operation of the handlebar and the steering column	Handlebar and stem assembly	Static load test (longitudinal/ vertical)	1600 N (Stage 1), 2600 N (Stage 2)	Two stage test. Stage 1: a static force is applied for 1 minutes at the centre of the handlebars at 45 ° from vertical in the forward direction. Stage 2: a progressively increasing force is applied at 45 ° from vertical in the forward direction until either the maximum force or 50 mm deflection is reached	Stage 1, there shall be no cracks, fracture or permanent deformation greater than 10 mm. For Stage 2, there shall be no cracks or fractures

E-scooter Tested part	E-scooter Load	E-scooter Type of test	E-scooter Test summary	E-scooter Requirement	EAPC Tested part	EAPC Type of test	EAPC Load	EAPC Test summary	EAPC Requirement
Handlebar and steering column	50 kg (490.5 N)	Static load test (vertical)	Static load divided equally and applied for 1 minute vertically, separately, upward and downward at the centre of each side of the handlebars i.e. 25 kg on each handlebar	No cracks, fractures or deterioration of the operation of the handlebar or steering column, nor movement of the telescopic part					
					Handlebar and stem assembly	Static lateral bending test	800 N	Static load applied 50mm from the end of the handlebar to simulate the force of the rider pushing down with their full weight on one hand	No cracks, fracture or permanent deformation greater than 15 mm
Handlebar and steering column	20 Nm	Static torque test	Torque applied in each possible direction of rotation for 1 minute while the fork is prevented from rotating	No movement of the handlebar stem in relation to the steering tube	Handlebar and stem assembly	Static torque test	40 Nm	Torque applied in each possible direction of rotation for 1 minute while the fork is prevented from rotating	No movement of the handlebar stem relative to the fork steerer

E-scooter Tested part	E-scooter Load	E-scooter Type of test	E-scooter Test summary	E-scooter Requirement	EAPC Tested part	EAPC Type of test	EAPC Load	EAPC Test summary	EAPC Requirement
					Handlebar and stem assembly	Static torque test	70 Nm	A torque is applied to attempt to twist the handlebar around its axis in the stem, simulating the rider leaning heavily on cranked handlebars	No movement of the handlebar relative to the handlebar stem
Handlebar grips and plugs	70 N	Static load test	Static force applied to the handlebar grip and plug for 1 minute to test whether the grip or plug slides off	The grips and plugs shall withstand the dismantling force	Handlebar grips and plugs	Static load test (cold condition)	70 N	Static load applied to the handlebar grip and plug under freezing conditions to check whether the grip or plug slide off	The handlebar grips or plugs shall withstand the specified removal forces
					Handlebar grips and plugs	Static load test (hot condition)	100 N	Static load applied to the handlebar grip and plug after heating to 60 °C and cooling to room temperature to check whether the grip or plug slide off	The handlebar grips or plugs shall withstand the specified removal forces

E-scooter Tested part	E-scooter Load	E-scooter Type of test	E-scooter Test summary	E-scooter Requirement	EAPC Tested part	EAPC Type of test	EAPC Load	EAPC Test summary	EAPC Requirement
					Bar ends	Static torque test	300 N	A static force is applied in one of three positions depending on the length of the bar ends to test whether the bar ends rotate relative to the handlebar	No movement of the bar end in relation to the handlebar
					Saddle/ seat post	Static load test	650 N	Static load applied vertically downwards 25 mm from either the front or rear edge of the saddle for 1 minute	No saddle deformation or failure of any component
					Saddle/ seat post	Static load test	250 N	Static load applied horizontally 25 mm from either the front or rear edge of the saddle for 1 minute	No saddle deformation or failure of any component

E-scooter Tested part	E-scooter Load	E-scooter Type of test	E-scooter Test summary	E-scooter Requirement	EAPC Tested part	EAPC Type of test	EAPC Load	EAPC Test summary	EAPC Requirement
					Saddle/ seat post	Static load test	400 N	Static load applied vertically upwards 25 mm from either the front or rear edge of the saddle	Saddle cover shall not disengage; no permanent distortion of the saddle assembly

Table 9: Fatigue testing required for e-scooters in BS EN 17128:2020

Tested part	Test summary	Force	No of test cycles	Type of test	Requirement
Frame/deck/front fork/steering assembly	The scooter is restrained via the rear axle while the front wheel runs on a drum with ramps which are spaced around its circumference such that one ramp is encountered every 1.5 seconds (0.66…Hz)	110 kg (100 kg on footplate, 10 kg on the centre of the handlebars) (Dynamic load approximately 1,924 N)	20,833	Vertical forces	No visible cracks or fractures

Table 10: Fatigue testing required for EAPCs in BS EN15194:2017

Tested part	Test summary (Maximum test frequency of 10Hz)	Force	No of test cycles	Type of test	Requirement
Frame	A force replicating the combination of rider weight on the pedals and the resulting tension in the chainstays is cyclically applied via a dummy pedal and crank assembly. The test loads both pedals simultaneously and thus does not seek to replicate the cyclic side to side loading associated with pedalling.	2,000 N (1,000 N applied to each pedal)	100,000	Pedalling forces	No cracks or fractures in the frame. For composite frames, running displacements not to increase by more than 20 %
Frame	The frame is restrained via the rear axle and cyclically loaded fore and aft through the front fork, which can be a stiff dummy unit, replicating the forces associated with encountering obstacles like potholes	+/-600 N (front wheel drive) +/-500 N (rear or centre drive)	100,000	Horizontal forces	No cracks or fractures in the frame. For composite frames, running displacements not to increase by more than 20 %
Frame	The frame is secured via the rear axle while the front is permitted to move fore and aft on a roller which replaces the front wheel. A cyclical load is applied to a structure which replicates the saddle and seatpost assembly to replicate the load of a rider bouncing on the saddle.	1100 N	50,000	Vertical forces	No cracks or fractures in the frame. For composite frames, running displacements not to increase by more than 20 %
Handlebars and stem	Two stage test. Stage 1: the handlebars and stem assembly are clamped and out of phase fully reversing cyclical loads are applied to each handlebar 50 mm from the outboard ends in a manner that replicates the forces generated by a rider pushing and pulling on the handlebars as they pedal.	+/-220 N per side (out of phase)	100,000	Vertical forces	No visible cracks or fractures; for composites handlebars or stems, the running displacements shall not increase by more than 20 % of the initial values
Handlebars and stem	Stage 2: cyclical loads are applied to the handlebars 50 mm from their outboard ends in a manner that replicates the load generated by the rider as they support their weight on the handlebars while riding over bumps in the road.	+/- 280 N per side (in phase)	100,000	Vertical forces	No visible cracks or fractures; for composites handlebars or stems, the running displacements shall not increase by more than 20 % of the initial values

Tested part	Test summary (Maximum test frequency of 10Hz)	Force	No of test cycles	Type of test	Requirement
Front fork	The front fork is restrained and cyclically loaded in the fore and aft direction to replicate the forces generated by encountering obstacles such as potholes	500 N	100,000	Bending fatigue plus rearward impact test	For non-composite forks, no fractures or permanent deformation greater than 45 mm; for composite forks, the running displacement shall not increase by more than 20 % of the initial values.
Front fork brake mount	A fixture replicating the front brake assembly is fixed to the front fork and cyclically loaded to replicate the forces transmitted to the fork through braking.	600 N	12,000	Fork for hub/disc-brake - (Brake mount fatigue test)	No cracks or fractures, for suspension forks, there shall be no separation of any parts)

7 Stability requirements

E-scooters have developed a reputation for being unstable. Standing e-scooters have a tendency to be longitudinally unstable because they typically have a short wheelbase and high centre of gravity, due to the relatively heavy mass of the rider compared to the typically much lighter vehicle, which makes them prone to pitching forward when they encounter an obstacle such as a pothole or kerb, or under heavy braking. Unlike pedal cycles, where the rider is closely coupled to the machine via the saddle and pedals, the motion of standing e-scooter riders is much less closely linked to the motion of the machine. However, the dynamic behaviour of the rider is crucial to maintaining stability. It is therefore very difficult to measure the stability of two-wheeled, standing e-scooters independently of the rider and thus create truly objective metrics for stability.

7.1 Bicycle and EAPC stability tests

7.1.1 BS EN ISO 4210-3:2023 Cycles — Safety requirements for bicycles

This international standard specifies a steering flutter test, with the requirement that “the bicycle shall not oscillate with increasing frequency and/or amplitude, either with or without excitation at the handlebar”. The method specifies a range of parameters, including speeds, gradients, and how the rider shall obtain the vibration excitation of the steering. The method also specifies a test featuring a payload on the bike.

7.1.2 BS EN 15194:2017 Electrically assisted pedal cycles

This standard contains a basic requirement for the steering to be ‘free to turn through at least 60 ° either side of the straight-ahead position and shall exhibit no tight spots, stiffness or slackness in the bearings when correctly adjusted’, tested by a rider turning the handlebars. There is also a further road test requirement for a fully assembled EAPC that must result in the demonstration of ‘exhibit stable handling in braking, turning and steering, and it shall be possible to ride with one hand removed from the handlebar (as when giving hand signals), without difficulty of operation or hazard to the rider’. The test method itself is essentially a straightforward test ride, with certain parameters met.

7.2 Stability tests for e-scooters

In the eKFV approval scheme for e-scooters and other personal electric vehicles, the German authorities have attempted to regulate the stability and controllability of e-scooters using a series of practical tests which are intended to replicate real world riding conditions. The test has four different test obstacles which must be driven over without losing stability or control such that the direction of travel deviates by more than 20 ° from the intended path. The test obstacles have been designed to replicate road features that might be encountered in use:

- a 50mm deep pothole with a vertical entry and ramped exit (Figure 2),
- a 20 mm deep pothole with vertical entry and exit (Figure 3),

- a warped ramp in which the riding surface ramps up 100 mm in two planes simultaneously (Figure 4),
- a 30 mm high kerb with a 20mm radiused edge (Figure 5) which must be traversed at both 45 ° and 90 °.

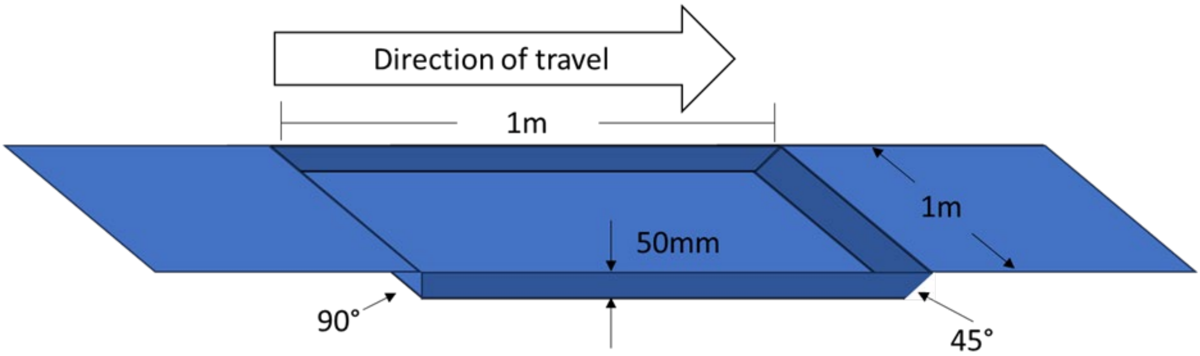

Figure 2: eKFV obstacle #1 - pothole with vertical entry and ramped exit

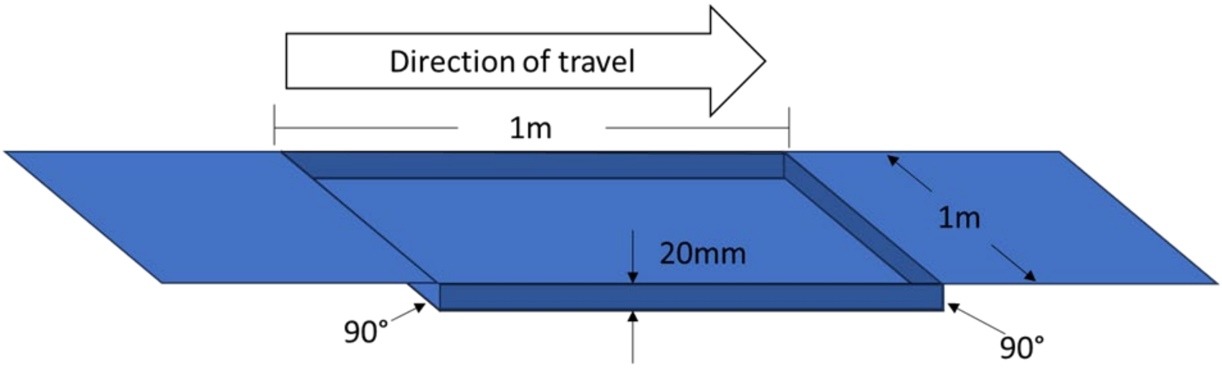

Figure 3: eKFV obstacle #2 - pothole with vertical entry and exit

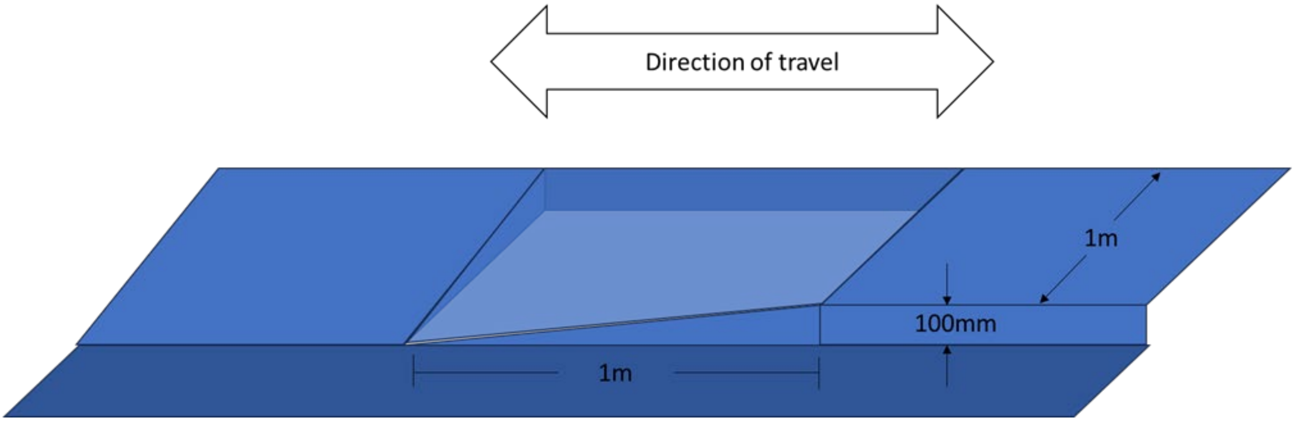

Figure 4: eKFV obstacle #3 - warped ramp

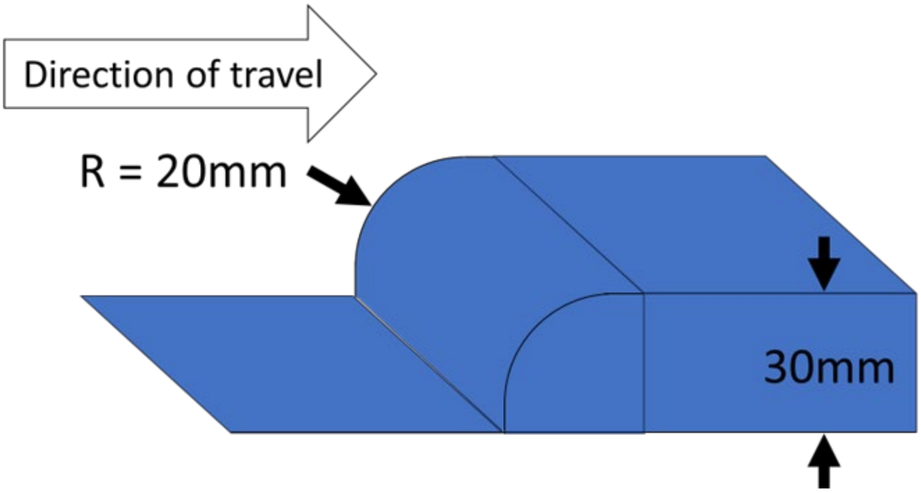

Figure 5: eKFV obstacle #4 – kerb

The obstacles must be crossed at both 8 km/h +/-2 and at the maximum design speed. Machines with more than two wheels must be driven across obstacles 1, 2 and 3 with all wheels first, and then with only the wheels on one side on the obstacle.

The stability tests developed by the German authorities have also been adopted, unchanged, by Spain (the ‘Manual of characteristics of personal mobility vehicles’, or VMP) and have been used in the UK for the approval of e-scooters used in the ongoing rental trial (GOV.UK, 2023b). By contrast BS EN17128:2020 takes a rather more prescriptive approach by specifying a number of design features linked to stability, including the size of the footrest/deck (min 150cm2), the coefficient of static friction of the tyres (min μ = 0.3), and the diameter and width of the front tyre (125 mm x 25 mm). The standard also specifies a detailed set of braking tests, which include requirements that the machine must be stable under braking. In addition to the obstacle tests, the Spanish regulations also specify a minimum front wheel diameter of 203.2mm, while the German regulations make no stipulation about wheel size.

While the German eKFV standard does not seem to have been formally validated against other alternatives, the degree to which it is being used and adopted indicate that it at least provides a reasonable baseline for e-scooter stability. There however remains concern regarding the longitudinal stability of e-scooters and their propensity to cause head and facial injuries. This lack of longitudinal stability is of particular concern given that e-scooters are often, of necessity, ridden along the edge of the road where they are highly likely to encounter drain covers, kerbs and other obstacles likely to cause longitudinal upset. There are design decisions which can be taken to improve longitudinal stability, including lowering the centre of gravity of the machine by fitting the heaviest components under the footplate, extending the wheelbase and making the wheels larger to reduce the pitching effect of obstacles. However, prescribing certain design decisions would limit the choices that could be made by designers to improve the overall stability and performance of e-scooters and thus potentially prevent the evolution of better new designs.

8 Acceleration and hill climb performance of e-scooters

8.1 Introduction

This chapter addresses the acceleration and hill climb performance of e-scooters. Defining maximum limits for e-scooter straight line performance metrics needs to carefully balance desired outcomes including the ability to travel up hills, being able to safely move at similar speeds and accelerations to road users sharing the same space, and having predictable behaviours to ensure safe interactions between e-scooter riders, pedestrians and other road users.

There are a number of attributes that make up the ‘straight line’ performance of a vehicle, including speed, acceleration, jerk, smoothness and gradeability. They are all interdependent as they rely on the same hardware (battery, inverter and electric motor) and software performance. This results in the need to balance the requirements of greater performance needed to propel the vehicle up inclines, and the specification of performance limits to ensure safe acceleration, while considering that the mass of one user could easily be twice that of another one.

8.2 Performance attributes and measurements

8.2.1 Velocity

Maximum velocity or speed is normally reached when the vehicle’s aerodynamic drag (along with other resistive forces) equals the maximum driving thrust. With e-scooters, there is often a speed limiter, normally controlled by software in the speed controller, that prevents the electric motor exceeding a defined maximum rotational velocity. Vehicle speed is measured in metres per second (m/s), or more commonly km/h or mph.

8.2.2 Acceleration

Acceleration is the rate of change of speed. It is closely related to the vehicle torque and is also proportional to the system (vehicle, rider and any cargo) mass. Its units are m/s^2, but G is also sometimes referred to. BS EN17128:2020 sets acceleration requirements for Personal Light Electric Vehicles (PLEVs) – which includes e-scooters - as “smooth without shocks” and “limited to 2 m/s^2” in order to avoid “unstable riding conditions”.

8.2.3 Jerk

There are other attributes including driveability (how easy it is to control the vehicle using the accelerator or “throttle”, or other characteristics like sportiness or comfort) and efficiency (how much energy the vehicle uses to travel a given distance or drive cycle) that are closely related to performance.

One driveability attribute that is particularly important is the rate of change of acceleration, sometimes referred to as jerk. The rate of change of acceleration is responsible for the jerking movements when the accelerator or throttle is applied, this can result in unwanted vehicle behaviours such as poor comfort, controllability, or loss of traction. While this will have a hardware limit, it is typically software controlled by limiting the rate of change of torque generated by the motor.

Lower jerk typically feels more comfortable and slower to respond, higher jerk can give a sporty feel. Very high jerk rates are uncomfortable and difficult to control, can cause wheelspin and can damage drivetrain components. Jerk has no impact on the maximum acceleration, but does influence the perceived acceleration and responsiveness of the vehicle.

8.2.4 Gradeability

Gradeability, or hill climbing capability, is the speed at which a vehicle can accelerate to, or maintain, up a gradient. It is closely related to vehicle torque and is also proportional to the system mass. In UK towns and cities, there are often roads with gradients of around 8-10 % as this is deemed acceptable for incorporating carriageways into developments according to the Highways Guidance on Gradients. There are steeper streets of around 20 % common in cities like Bristol and Sheffield, although these can often be avoided.

8.2.5 Torque

Torque is the force that accelerates a vehicle, pushes a vehicle up a gradient or overcomes resistive forces. For electric motors it is not constant over the speed range, reducing as speed increases. Vehicle torque can be increased using reduction gearing, this increases the torque at the wheel (and therefore acceleration and hill climbing capability) while reducing speed proportionally. The unit for torque is Newton metres (Nm).

8.2.6 Power

Power is the multiple of torque and speed. For propulsion systems it is often described graphically using torque speed profiles. It also varies with time with peak power normally measured for a small number of seconds, and continuous power measured for an indefinite or longer period (usually based on the typical duty cycle for the application of the propulsion system). The unit for power is Watts (W).

8.2.6.1 Peak power

As peak power is measured over a small number of seconds is it a useful indicator for short bursts of vehicle performance, like a short acceleration to pull away from standstill or perform an overtaking manoeuvre, or for travelling up a short incline. Peak power will be limited by vehicle hardware, including the voltage of the battery (which will itself be affected by state of charge) and the current rating of the speed controller (sometimes referred to as the inverter). This is the input electrical power going into the motor, the motor will then convert this to kinetic power in the form of torque and speed (and efficiency losses, the majority of which are heat).

8.2.6.2 Continuous power

Continuous power, being a measure of an indefinite (or more usually longer) period, is an indicator for sustained effort only, like travelling up a very long hill. It is significantly less than peak power and is limited by the electric motor's thermal performance; its ability to dissipate the heat generated when converting electrical to kinetic energy.

8.2.7 Duty cycle

The duty cycle, or drive cycle, of a vehicle defines how that vehicle is used or operated for a given journey. It represents a journey as torque and speed profiles over time.

8.3 Measuring peak and continuous power

Power rating claims on e-scooters vary considerably and the validity and usefulness of them should be questioned. Continuous power ratings are conveniently round numbers of 250, 350 or 500 W (including the e-scooters tested during this investigation), rather than a true continuous maximum power. Peak power rating claims are provided by manufacturers/retailers less frequently. In some cases it is not clear whether the claimed power is continuous or peak.

There are two texts identified for measurement of continuous and peak power, standard EN60034-1 (Rotating electrical machines, Part 1: Rating and performance) and UN/ECE Regulation No 85 (Uniform provisions concerning the approval of internal combustion engines or electric drive trains intended for the propulsion of motor vehicles of categories M and N with regard to the measurement of net power and the maximum 30 minutes power of electric drive trains).

EN60034-1 provides a method for measurement of a minimum continuous power (over a continuous running duty, or by selecting a duty type that is no less onerous than the expected duty), typically for industrial machinery to ensure that electrical machines meet the minimum duty requirements of an application. If an electrical machine can comfortably meet these requirements it would pass, therefore an electrical machine could have a significantly higher continuous power rating. In practice, for industrial applications this electrical machine would be larger/heavier, more expensive and potentially less efficient so unlikely to be used in the application. Therefore, this is not an appropriate method for rating maximum continuous power.

UN ECE Regulation No 85 is written for M category (vehicles having at least four wheels and used for the carriage of passengers) and N category (vehicles having at least four wheels and used for the carriage of goods) vehicles, and covers electric and internal combustion engine vehicles, but is referenced by Regulation (EU) No 168/2013 on the approval and market surveillance of two- or three-wheel vehicles and quadricycles. It is important to note that neither M or N vehicles specify maximum power limits, but it may be advantageous for manufacturers to produce a power claim as high as possible to show vehicles are capable.

It provides a method for measurement of peak power (referred to as net power) to produce a power curve. This test runs the motor for three minutes at 80 % of maximum power recommended by the manufacturer, before running at the full setting of the power controller between zero and the higher recommended motor speed to determine the power curve. This test must be completed within five minutes. Eight minutes of high power running of a small motor is not representative of the peak power duty from real world use of e-scooters, and the motor or power controller may have de-rated (either by reaching a thermal limit, or through software control) before the test is complete. Therefore, this measurement is likely to produce lower peak power ratings than what is relevant for e-scooter use cases such as accelerations lasting a few seconds.

The peak power measured value is then used to set the motor speed for the maximum continuous power test (referred to as 30 minutes power). In this test the electric drive train (motor and power controller) is run at a power which is the best estimate of the manufacturer for the maximum 30 minutes power at a speed recommended by the manufacturer. The maximum 30 minutes power is the average of the power within the 30 minutes period.

With the power set point being a "best estimate" of the manufacturer and the speed set point being recommended by the manufacturer the test could be run, and is easier to run, at any lower power value, hence why continuous power ratings of e-scooters (and EAPCs) are often round numbers and may not relate to real-world vehicle performance.

EN17128:2020 does not state a power limit (continuous or peak), instead it specifies an acceleration limit and states:

> *"…vehicles are intended to be used for last mile and need to be portable… the portability limits the mass and the size of the batteries and the motor and thus the power…*
>
> *For the reasons given no power limit is required."*

8.4 Power limits on other vehicles

8.4.1 Motorcycles and other L-category vehicles

Motorcycles have traditionally used a continuous power limit to limit the performance of vehicles in different categories. This was originally defined as the continuous power limit in an internal combustion engine, which is very similar to the peak power limit (and prior to this the test was written to provide a power claim for M and N category vehicles that have no requirements for maximum power limits, as previously discussed). With the shift to battery electric vehicles, the use of continuous power to limit performance has continued, but this has resulted in electric vehicles that have significantly more peak power (and therefore acceleration) than their internal combustion counterparts due to electric powered motorcycles having higher peak power than continuous power.

8.4.2 Electric Assist Pedal Cycles (EAPCs)

Electric Assist Pedal Cycles (EAPCs) have a continuous power limit for their electric assist systems of 250 W. This is in addition to the rider's power output. It is important to note that the rider's power output will vary significantly due the difference in cardiovascular fitness and leg strength, but a heavier rider will generally be able to output a higher power than a lighter rider (at least for short bursts), and therefore attributes affected by mass, like acceleration and gradeability, are not as negatively impacted by this increase in mass. This is not the case for e-scooters that rely solely on the electric motor for traction power.

8.5 Hill climb test method

In order to understand real world e-scooter straight line performance, specifically acceleration and hill climbing capability, along with the relevance of claimed continuous and peak power ratings, a series of tests were conducted on a range of commercially available e-scooters. This section outlines the method that was employed.

8.5.1 Test facility requirements

To perform the test a location was identified that met the following requirements for the two types of test: 1) a flat acceleration test, and 2) a hill climb test.

8.5.1.1 Flat acceleration test

- Private land with permission of landowner
- Flat (less than 0.5 % gradient)
- Length of at least 400 m
- Good quality road surface
- Wind speed less than 3 m/s

8.5.1.2 Hill climb test

- Private land with permission of landowner
- Appropriate consistent gradient (at least 8 %) to challenge vehicle performance
- Length of at least 400 m
- Good quality road surface
- Wind speed less than 3 m/s

8.5.2 Test samples

Nine e-scooters of varying performance, with claimed continuous powers of between 250 W and 500 W, were obtained for the testing. The vehicles tested were from various different manufacturers, with some of them used in shared e-scooter schemes such as those being trialled in different areas of the UK, whilst other e-scooter models were available for purchase from high-street and/or online retailers.

The e-scooters all had minimal mileage completed on them, so the impacts of wear and tear on performance were assumed to be negligible. The e-scooters were of varying performance levels, included privately-owned and fleet-managed rental vehicles, and were of varying masses and power outputs. Table 11 shows the key performance characteristics of each e-scooter tested. Where available, claimed maximum speeds along with continuous power and peak power ratings have been included.

Table 11: Summary of the key claimed data for each e-scooter tested (information based on manufacturer-provided data)

Make and Model	Vehicle Type	VMax (km/h)	Mass (kg)	Rated Power (W)	Peak Power (W)	Battery Capacity (Wh)	Driven Wheel
Scooter A	Private	33	13.7	350	N/A	460	Rear
Scooter B	Private	30	11.6	500	N/A	280	Front
Scooter C	Private	25	19.1	350	800	551	Rear
Scooter D	Private	35	15	500	700	465	Rear
Scooter E	Private	18	12.5	250	N/A	200	Rear
Scooter F	Private	25	17.5	350	515	468	Rear
Scooter G	Shared	21	N/A	N/A	N/A	N/A	Rear
Scooter H	Shared	21	34	350	N/A	705.6	Rear
Scooter I	Private	25	14.1	250	N/A	270	Front

8.5.3 Instrumentation

For each test, a VBOX Sport data logger was used to enable collection of data, with obtained data including the speed of the vehicle as well as the location of the vehicle in terms of latitude, longitude and altitude.

The VBOX Sport was mounted to the front of the e-scooters using a secure phone mount. In most cases this was on the handlebars, but due to the larger size and non-uniform shape of Scooters G and H the logger was mounted on the battery at the front of the footplate. Data were recorded at a frequency of 10 Hz.

Location data are gathered with an accuracy in longitude and latitude of 2 metres, sufficient for the tests being conducted. Division of the recorded VBOX latitude data by 60 and longitude data by -60 enabled the real-world latitude and longitude metrics to be measured, in degrees, and therefore plotted on a map to outline the route taken by each vehicle and the speed and acceleration at each point on the route. This enabled segmentation of the route so that specific sections of the route, with the most consistent gradient, could be assessed.

8.5.4 Test 1 – Flat acceleration

Test 1 considered the performance of the e-scooter on flat ground (less than 0.5 % gradient) from a standing start. The purpose of this test was to obtain benchmark data for the performance characteristics of the various e-scooters being used in this evaluation. Each e-scooter started off stationary, at the same point and accelerated in a straight line up to its top speed (Vmax). At the end of the route, the e-scooter was then ridden along the same route in the other direction, again from a standing start up to its top speed. The test was conducted in both directions aligning with typical standards for flat acceleration and top-speed vehicle testing and to ensure that differences in aspects such head or tail winds, or slight incline/decline on the road, can be cancelled out by taking an average of the two directions. As e-scooters do not typically provide propulsion from standstill, the rider is required to push off before electrical power starts when the vehicle exceeds a minimum speed – this varies between vehicles but in all cases was less than 5 km/h.

From this test, the relationships between power and acceleration at different speeds was reviewed.

8.5.5 Test 2 – Hill climb

Test 2 assessed how each of the e-scooters in the sample was able to climb the test hill. The test hill was chosen to be typical to those seen in more hilly UK cities such as Bristol and Sheffield. The full test hill was over a distance of approximately 650m with an elevation change of approximately 40 m. Sections of the hill reached gradients of approximately 10 % according to online route planner Komoot. The site is a privately owned and managed by Bristol City Council, who granted permission for the use of the facility for the tests conducted.

Each e-scooter was ridden continuously up the test hill, from a standing start, in the highest power mode available to the rider and at full power demand for the course of the test. The rider was kept the same for each test, and had a measured mass of 70 kg. The test rider mass of 70 kg is representative for UK women (with a mean mass of 71.8 kg) but significantly less than men (mean mass 85.4 kg) – from a 2021 NHS survey. A 20 % increase in rider mass would have a proportional decrease to the vehicle acceleration, hill climbing capability and increased energy usage, and vice versa for lighter riders. Maintaining a consistent rider mass across all vehicles is critical for repeatability. Adding a ballast to increase the mass of the rider, and potentially run the tests at two mass points, was not done as a significant enough mass increase (at least 20 kg, either carried by the rider or fixed to the e-scooter) may have negatively impacted the steering, handling and safe use of the vehicle, which are not designed to carry such loads.

Segmentation of the route using mapping tools was used to define consistent start and finish points for assessment and evaluation of e-scooter performance. Hill climbing performance was assessed subjectively and objectively based on the speed and deceleration of the vehicle due to the gradient of the incline, where full power was insufficient to maintain constant speed.

8.5.6 Vehicle and test conditions

Prior to each test, the e-scooter batteries were fully charged and safety checks on the vehicles were performed.

The state of charge of the battery has a significant impact on the performance of an e-scooter. Therefore, during the tests the state of charge of each vehicle was monitored and recorded. Uphill testing was not conducted on scooters where the performance seemed to be declining due to the battery life or where the state of charge displayed dropped below 50 %.

Weather conditions including precipitation, visibility, temperature and wind speed were assessed on the day to ensure they did not significantly impact the testing, and remained consistent for all vehicles. The road was mostly dry on both days of physical testing, but where the ground was damp or wet, this information was recorded. Subjective observations of ground and weather conditions were recorded during the tests.

A full risk assessment identifying and mitigating all people, vehicle and test hazards, was produced and signed-off by the project team prior to the tests commencing. Mitigations were put in place to ensure the safety of the test-rider and any other test support team member, along with any members of the public in the vicinity of the test location.

Key mitigations included the use of suitable personal protective equipment (cycling helmet, gloves, high visibility clothing, full length sleeves and trousers), safety checks and familiarisation with all test vehicles prior to testing, and the use of a lead EAPC ridden by a supporting team member to form a rolling test zone for the e-scooter tests.

8.6 Data analysis

8.6.1 Determination of route for hill climb test

For the hill climb test, the full route which was used for completing each test run had a length of approximately 650 metres. This route had areas of different gradients and features including speed humps which impacted the speed and the stability of the e-scooter when it was being used to ride uphill. To enable reliable results to be obtained from the hill climb tests, it was important to identify a section of the route where there were no features (such as potholes or speed bumps) which would influence the speed of the vehicle or the balance of the rider, and where each e-scooter would be able to achieve a speed close to its top speed (VMax) for a prolonged period. The gradient of the incline on the route must be such that it is clear in the data collected where the vehicle is either speed-limited or power-limited. This varies from vehicle to vehicle, but all vehicles tested exhibited power limited deceleration due to the test hill gradient. Speed-limited is defined as when the speed is unable to go beyond a certain point and therefore the speed-time graph flatlines, with power fluctuating or de-rating to prevent the vehicle from exceeding a speed limit. Power-limited is defined as when the graph of the relationship between power and time flatlines, and the speed of the vehicle as a result decreases because the vehicle motor is unable to deliver more power to enable speed to be maintained. On steeper hill sections, an e-scooter is more likely to be power-limited – i.e. unable to deliver more power to maintain the speed travelling uphill.

The selection of a suitable section of the route was aided using the geolocation software Google Earth. The line drawing tool on Google Earth was used to draw two lines – a starting line and a finishing line – on the map of the route. The lines were perpendicular to the direction of the road and drawn onto a map showing satellite images of the route. For both lines, the latitude and longitude coordinates of two points along the line were recorded, allowing the linear equation of each line, represented in the format y = m x + c, to be determined. The equations for the start line and the finish line are outlined in Equation 1 and Equation 2, respectively:

$$Longitude = \frac{59}{26} Latitude - 119.3807373$$

Equation 1: Linear equation for the starting line of the assessed route for the hill climb test

$$Longitude = \frac{-64}{17} Latitude + 191.0254968$$

Equation 2: Linear equation for the finishing line of the assessed route for the hill climb test

For each hill climb test run, the latitude and longitude location data collected by the VBOX data logger was converted into degrees using calculation tools in Microsoft Excel. Following this, it was possible to use Excel to identify where the location of each test e-scooter intersected the starting line and the finishing line. For the hill climb test, data was included for a valid run only for the time between the location of the e-scooter first intersecting the starting line, until the first point where the path of the e-scooter intersected the finishing line. If GPS accuracy was not good enough to intersect the start or finish lines, or the test was aborted the data was not used.

The assessed data was then verified using the 3D maps tool in Microsoft Excel. When verified, a mean route length of 166.88 m was observed, with a standard deviation (σ) of 2.88 m. The use of 3D maps also verified that, whilst there were differences in the exact path taken by each e-scooter on each hill climb run, the differences in the overall length of the run completed by each e-scooter was negligible.

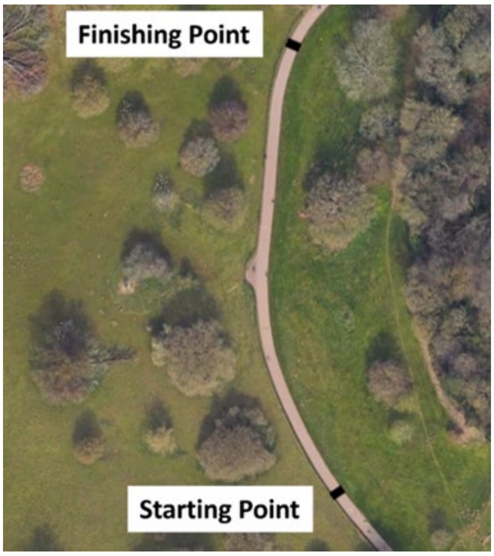

Figure 6: An aerial view of the starting and finishing points identified on the hill-climb run

Due to excessive noise and variability in the altitude measurement from the logged test data, the hill climb route elevation was also surveyed at 5 m intervals to produce the following elevation profile.

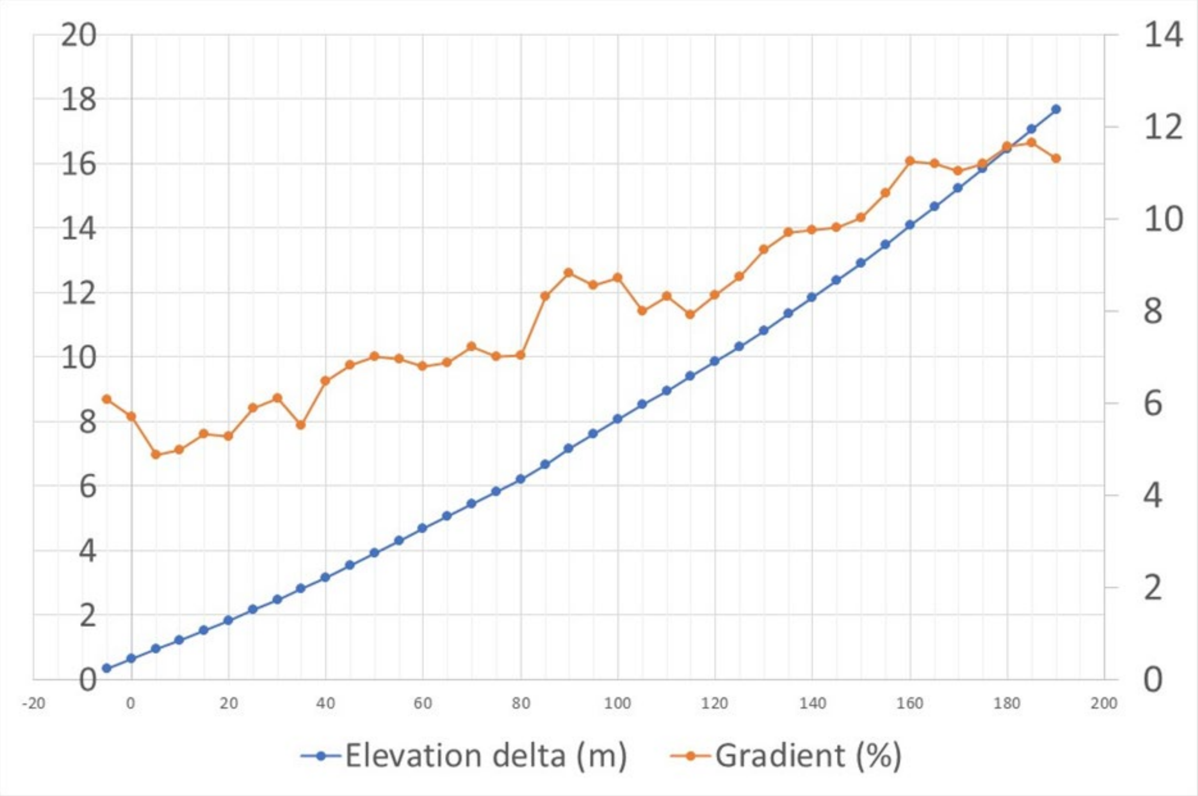

Figure 7: Surveyed elevation delta profile and calculated gradient

8.6.2 Power calculation

For all tests, it was important to calculate the power output of each e-scooter. A model was produced, using Microsoft Excel, which enabled the instantaneous power of each e-scooter to be derived.

To calculate power, an equation was produced based on first principles. The power resulting from a moving object is the product of the magnitude of the force propelling the object forward and the velocity at which the object is moving. In the case of an e-scooter being ridden, this propulsion force is referred to as the driving force.

To determine the forces acting on the e-scooter being operated by the rider, a free-body diagram can be produced. The free-body diagram shows the e-scooter and rider, of total mass M, driving up a hill where the incline is of an angle, θ.

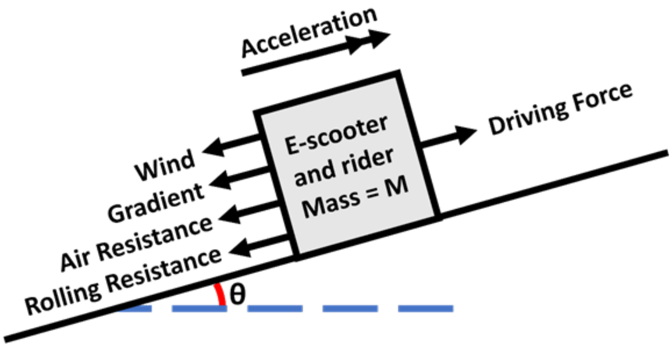

Figure 8: A free-body diagram of the forces acting on an e-scooter acting parallel to the direction of travel

The total driving force of the scooter ($F_{Driving}$, unit = N) is equal to the sum of all the forces acting against it and the resultant force ($F_{Resultant}$, unit = N). The resultant force is the product of the acceleration (a, unit = m/s^2) and the mass of the object accelerating (M, unit = kg).

The force of the wind acting on the e-scooter and rider is the product of the density of the air, the frontal area of the e-scooter and rider, and the square of the wind speed. Wind speed and direction were checked using Met Office weather forecasts in the morning, with very light winds and good, dry conditions on all test days. In this project, it has been assumed that the wind speed was negligible. Therefore, the assumption was made that the resistive force of the wind was negligible for all tests conducted. For acceleration tests, the fact that the tests were conducted in both directions cancelled out any impact of wind speed, but this could not be done for uphill tests.

The force from the gradient (F_g, unit = N) of the incline is the product of the total mass of the object (M, unit = kg), the acceleration due to gravity (g, unit = m/s^2) and the sine of the angle of inclination, θ. The sine value for the angle θ can be calculated from the gradient of the hill using the Sine Rule, and since it is the sine value of the angle required, Equation 3 can be used to determine the value of Sine(θ) from the gradient, where y is equal to the gradient.

$$Sine(\theta) = (\left(\frac{1}{y}\right)^2 + 1)^{-0.5}$$

Equation 3: Conversion of gradient, y, into the Sine value of the angle of inclination

Air resistance force (F_a, unit = N) is half of the product of the coefficient of drag of the scooter and rider (CD), the density of the air (ρ_a), the frontal area of the e-scooter and rider (A) and the square of the speed of the scooter. The speed of the scooter (v) was extracted from the VBOX data output and converted from km/h into m/s using Excel.

Rolling resistance force (F_r, unit = N) is the product of the coefficient of rolling resistance (μ), the total mass of the e-scooter and rider (M) and the acceleration due to gravity (g).The combination of these equations produces Equation 4, which shows the total driving force of the e-scooter at a given time. Multiplication of this force by the velocity of the scooter produces Equation 5, which derives the power for the e-scooter. Inputting the measured velocity and acceleration data from the tests, taken at instantaneous points, this equation was then used to calculate the instantaneous power of the e-scooter in operation.

[redacted]

Equation 4: Calculation of instantaneous driving force of an e-scooter.

$$P = vF_{Driving} = v(MgSine(\theta) + \frac{1}{2}\rho_a AC_D v^2 + \mu Mg + Ma)$$

Equation 5: Calculation of instantaneous power of an e-scooter.

8.6.3 Data processing

Equation 5 was used on the data which was logged by the VBOX data logger to assess the instantaneous power of each e-scooter in each run conducted. For the hill-climb tests, the full equation was used for each test. However, for the flat testing, as part of the assumption that the route was perfectly flat, and with runs completed in both directions to account for any slight inclines, the term for the power to overcome the gradient was excluded (assumed to be zero).

To use Equation 5 to work out instantaneous power, some of the values in the equation had to be assumed, since data was not collected for these values. The values used are given in Table 12. The total mass of the vehicle (M, in kg) was the sum of the mass of the rider and the vehicle. The rider was measured to have a mass of 70 kg, whilst the vehicle mass was taken from the datasheets for each vehicle and verified by weighing the vehicle on weighing scales. The density of air (ρa) was assumed to be 1.225 kg m-3 at standard temperature and pressure (Helmenstine, 2023). The frontal area of the e-scooter and rider (A) is assumed to be a value of 0.65 m2 with the coefficient of drag (CD) assumed to be a value of 1.2 in an upright riding position. The coefficient of friction between the wheels of the vehicle and the ground is assumed to be a value of 0.0055, which a typical value for a BMX tyre (Roche, 1998).

Table 12: Values used in calculating e-scooter instantaneous power

Assumption / measurement	Value
Test rider mass	70 kg
Acceleration due to gravity	9.81 N kg^{-1}
Air density	1.225 kg m^{-3}
Frontal area	0.65 m^2
Drag coefficient	1.2
Rolling resistance coefficient	0.0055

Speed over time was extracted from the VBOX data logger, with speed recorded in km/h. Using the spreadsheet tools which were produced to complete instantaneous power calculations, the speed was converted into the SI unit for speed, metres per second (m/s), by creating a column which extracted the VBOX speed readings and dividing the values by 3.6. The VBOX logging equipment records the time to the nearest 0.1 second and takes readings at a frequency of 10 Hz. Since time was only required relative to the start of a particular run, once the data had been cropped either side of a useful segment of data, the time was assessed manually, letting the first row be the point where the time equalled zero, with time going up in 0.1 second increments from then.

The data from the VBOX data logger had noise which needed to be filtered out. Various methods were tried using data processing tools, including use of a rolling average, but since speed changes were too sudden for a one-second rolling average to be used, the use of a polynomial best fit of the relationship between velocity and time was deemed the most suitable way of filtering data. This was done using

MATLAB, since MATLAB can produce 10th degree polynomial best fits to 10 significant figures, whereas Excel is only capable of producing 6th degree polynomial best fit lines to lower accuracy. Tables of velocity-time data for each experiment were imported into MATLAB having been processed, the 10th degree polynomial for each individual test was calculated to 10 significant figures, and this data was then transferred into Excel manually for each test. The R-squared value for each polynomial fit of velocity-time data was also recorded since this information was useful in determining anomalous data.

With the equation for the polynomial best fit for the velocity-time relationship determined, acceleration-time data was produced by differentiation of the polynomial equation. This acceleration-time relationship was then used to determine the instantaneous acceleration of an e-scooter in a test.

To determine the total distance travelled by each e-scooter during a recorded test, the previous displacement reading was added by one-tenth of the velocity reading in the preceding column. The displacement was defined as zero for the first column, so displacement is always relative to the start of the captured data.

In order to calculate hill climb instantaneous power values, accurate gradient data is required. This is calculated from elevation data. Initially, the elevation data from the VBOX logged data, recorded in metres above sea level at a resolution of 0.1 metres, was considered for generation of an elevation profile, which would be consistent for all hill climb runs to ensure that the metric of calculated power could be comparable between different hill climb runs. Using all of the valid hill climb runs, over 7000 height measurements were obtained, and were assessed using a polynomial fit model. However, for the VBOX elevation data, the poor resolution, high variance in the elevation readings and high variance in elevation profiles over the completed runs meant that using such a method was not suitable for an accurate measurement of elevation. Therefore, surveying of the hill section at test location was determined as the best method to obtain elevation and gradient data. With the data collected in intervals of 5 metres, the difference in the elevation in metres over a 5-metre distance was divided by the difference in distance travelled to work out the gradient of the incline for each 5-metre section of the route.

The surveyed elevation data was used with the VBOX data to calculate instantaneous power values for the hill climb testing. This is not required for the flat acceleration tests.

8.6.4 Performance metrics

For the flat acceleration test, the acceleration and power of each e-scooter between specified speeds were the performance metrics of greatest importance. From a standstill, the rider would kick off the ground to propel the scooter before the throttle for the electric motor is used, and since the tests being conducted were to assess the scooter performance, it was important to reduce the likelihood of the rider physically propelling the scooter forward from influencing the results. Therefore, for low-velocity acceleration, the speed range was defined as between 5 km/h and 10 km/h. The maximum speed of the e-scooters was not consistent, with one not able to reach 20 km/h. Therefore, the high-velocity acceleration metrics were taken over a speed range of between 10 km/h and 15 km/h.

At the speed ranges of 5-10 km/h and 10-15 km/h, the peak instantaneous values for the acceleration of each e-scooter (unit = m/s^2) and power (unit = W) were recorded. Over these speed ranges, the mean acceleration and power values observed were also considered as performance metrics for each e-scooter. The maximum instantaneous power seen at any point over a run and the maximum speed (Vmax, unit = km/h), recorded by the VBOX logger over the course of a run were also measured.

8.7 Results

8.7.1 Test 1 - Flat acceleration

Table 13 shows the results for the performance metrics assessed in the flat acceleration testing. Where values provided are a peak value, the absolute maximum value from an individual run has been provided. Where mean values are stated, the value is a mean of the metric from all four of the test runs completed for each vehicle (two test runs in each direction).

Table 13: Summary of results from flat acceleration test runs for each e-scooter

Flat acceleration results	Scooter A	Scooter B	Scooter C	Scooter D	Scooter E	Scooter F	Scooter G	Scooter H	Scooter I
5-10 km/h peak acceleration (m/s^2)	1.96	1.16	1.31	2.10	1.26	1.80	1.67	2.09	1.28
10-15 km/h peak acceleration (m/s^2)	1.15	0.97	1.30	2.08	1.02	1.36	1.20	1.74	0.89
5-10 km/h mean acceleration (m/s^2)	0.91	0.66	0.97	1.52	0.34	1.08	1.30	1.79	0.45
10-15 km/h mean acceleration (m/s^2)	0.72	0.59	1.11	1.55	0.55	0.96	0.76	1.19	0.65
5-10 km/h peak power (W)	257.9	217.5	387.1	504.9	223.6	400.1	441.9	559.3	174.5
10-15 km/h peak power (W)	497.5	409.5	461.5	661.4	384.6	462.0	452.6	581.2	380.8
5-10 km/h mean power (W)	171.6	147.3	200.9	297.2	89.1	240.3	255.8	398.7	101.0
10-15 km/h mean power (W)	254.4	229.1	395.0	538.4	231.8	360.6	302.4	462.0	245.8
Max power (W)	570.6	574.7	488.4	661.4	384.6	478.2	563.5	581.2	496.3
Vmax (km/h)	24.0	24.0	23.5	24.4	19.9	24.6	19.8	21.1	22.5
5-10 km/h time (s)	1.55	2.14	1.77	0.95	4.20	1.88	1.08	0.78	3.53
10-15 km/h time (s)	1.98	2.55	1.26	0.91	2.80	1.48	1.86	1.23	2.17
Subjective assessment	*Adequate*	*Adequate*	*Adequate*	*Good*	*Adequate*	*Good*	*Adequate*	*Good*	*Adequate*

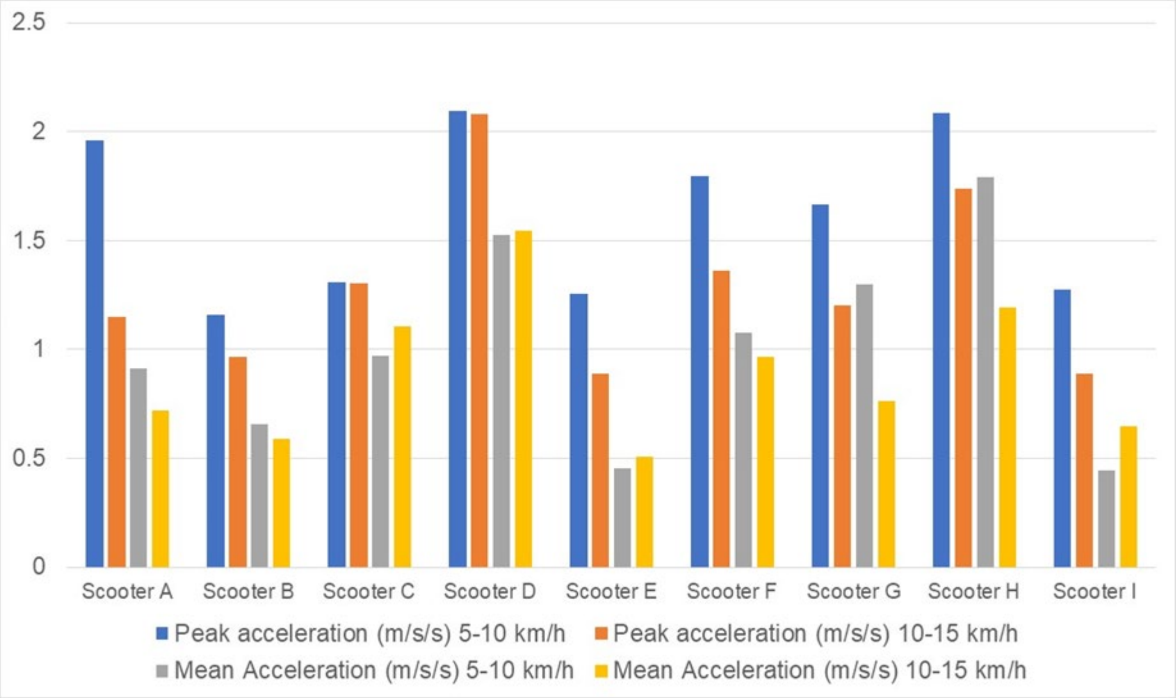

Figure 9: Comparison of measured e-scooter acceleration

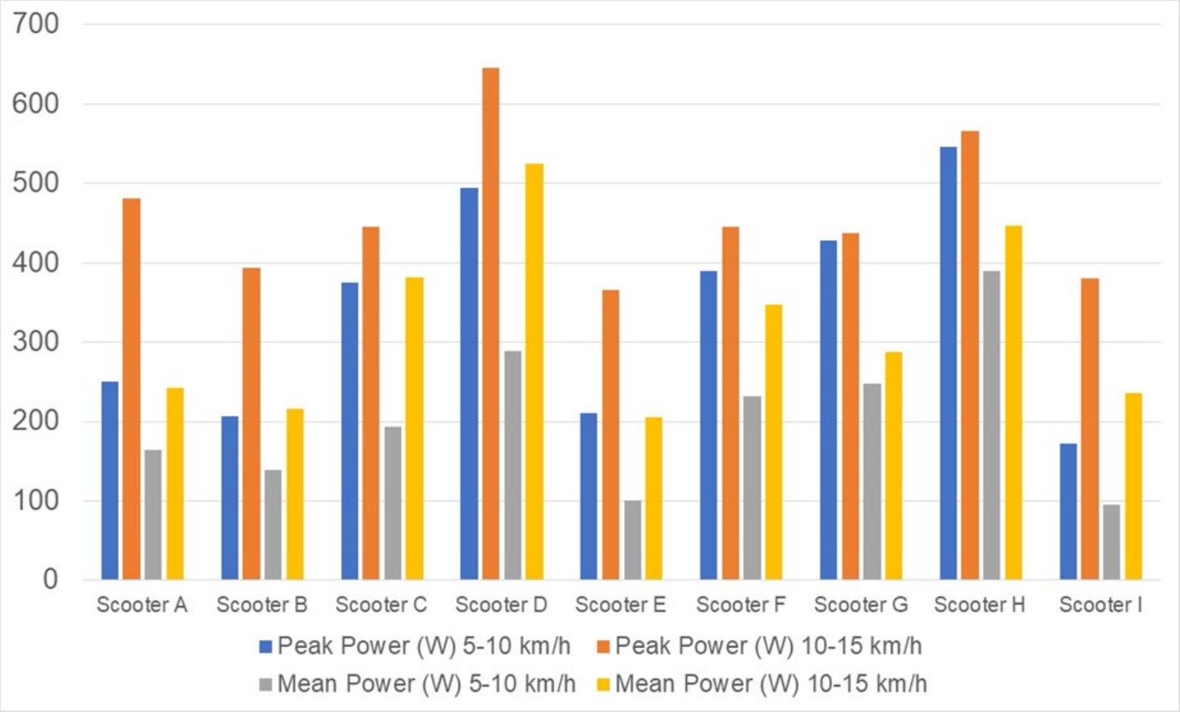

Figure 10: Comparison of calculated e-scooter power

8.7.2 Test 2 - Hill climb

Table 14 shows the results for the hill climb testing

Table 14: Summary of results from hill climb tests

Hill climb results	Scooter A	Scooter B	Scooter C	Scooter D	Scooter E	Scooter F	Scooter G	Scooter H	Scooter I
Hill climb minimum speed (km/h)	9.0	9.6	11.4	17.7	1.8	13.4	9.7	16.8	10.3
7% grade minimum speed (km/h)	15.4	15.9	16.9	20.3	7.6	14.1	15.1	18.7	17.5
7% grade power (W)	319	340	371	461	164	350	313	488	364
10% grade minimum speed (km/h)	12.0	12.8	13.3	19.5	1.8	13.9	11.6	18.0	12.4
10% grade power (W)	297	328	360	543	74	417	302	580	305
Subjective assessment	*Poor*	*Poor*	*Good*	*Good*	*Very poor*	*Good*	*Adequate*	*Good*	*Adequate*

Instantaneous power calculations are not shown due to unreliable logged elevation data resulting in inconsistent power values. Instead, sections of the hill test route with consistent gradient from the elevation survey (approximately 7% for 40m and 10% for 20m) have been used to calculate power.

8.8 Discussion

Table 15 below shows the combined hill climb and flat acceleration test results, including calculated power compared with the claimed power (continuous and peak).

Table 15: Combined hill climb and acceleration results

Test	Scooter A	Scooter B	Scooter C	Scooter D	Scooter E	Scooter F	Scooter G	Scooter H	Scooter I
Claimed continuous power (W)	350	500	350	250	250	350	350	350	250
Claimed peak power (W)	NA	NA	800	700	NA	515	NA	NA	NA
Calculated peak power (flat) (W)	497.5	409.5	461.5	661.4	384.6	462.0	452.6	581.2	380.8
Vmax flat (km/h)	24.0	24.0	23.5	24.4	19.9	24.6	19.8	21.1	22.5
Calculated power (hill) (W)	319	340	371	543	164	417	313	580	364
Hill climb minimum speed (km/h)	9.0	9.6	11.4	17.7	2.3	13.4	9.7	16.8	10.3
Subjective assessment	Poor	Poor	Good	Good	Very poor	Good	Adequate	Good	Adequate

8.8.1 Flat acceleration tests – key findings

Vehicle acceleration has been calculated from the acquired Vbox data. A range of acceleration is seen across the vehicles as described in the subjective assessment. Two of the vehicles (the Scooter D and Scooter H) exceeded the 2 m/s^2 limit specified in BS EN 17128:2020 by a small amount (less than 5%), with all other vehicles always below this limit and some lower powered vehicles less than half of this.

A number of power metrics were calculated to give values for the vehicle power. It is important to note that this is a vehicle 'whole system' power, rather than a motor or battery output power and so there will be differences to claimed power outputs from vehicle manufacturers and retailers.

Peak power over the 10 – 15 km/h acceleration range was selected as most representative of the acceleration performance of the vehicle. Over this range the vehicle is in a steady state of acceleration for a low duration of time (~2 s), representative of peak power measurement methods. It is less influenced by e-scooter push off dynamics and torque limiting control strategies. It is also in the constant power phase of the vehicle torque-speed profile, rather than at the lower speeds that may involve transitioning from constant torque to constant power phases.

While the vehicles tested had a range of acceleration levels, all of them provided at least adequate acceleration on the flat road test – none of the vehicles felt "too slow" as to make them unsuitable for use on flat roads. Therefore, a minimum level of acceleration on the flat is not a requirement. Likewise, none of the vehicles were perceived to accelerate at a level that felt unsafe. Acceleration performance variation between all the tested e-scooters on the flat didn't raise any subjective safety concerns, and proportional changes due to rider mass would not be significant when compared to the variation between the different performance e-scooters.

The faster accelerating vehicles tested (Scooter D and Scooter H) were easier to control, potentially owing to being more premium products with better torque control (software). These vehicles exhibited a gradual torque ramp when pulling away, so while acceleration was higher, the rate of change of acceleration (jerk) was subjectively perceived to be lower.

Sudden jerky accelerations were perceived on slower accelerating vehicles, particularly pulling away on the Scooter I and the Scooter A. The sudden and unpredictable torque delivery of these vehicles when attempting to pull away (applying the accelerator/throttle while manually scooting from stationary) often caught the test rider off guard.

Evaluation of the peak instantaneous powers observed and the mean power observed for each scooter showed that the ratings for motor power were reasonably accurate across the variety of scooters tested. This also verified that the equations used to assess the power of each e-scooter was suitable, with assumptions being made enabling a reasonable degree of accuracy to be achieved in the power calculations.

8.8.2 *Hill climb tests – key findings*

The test rider mass of 70 kg must be considered when discussing the hill climbing capability of the vehicle. Many of the vehicles have a maximum rider mass of 100 kg, with Scooter I claiming to have a maximum rider mass of 150 kg.

The gradient of the section of hill used had a mean gradient of approximately 8%, peaking at approximately 10 % in short sections.

The hill climb testing is where the performance differences between vehicles was most obvious. Even with a relatively low rider mass and modest average gradient of 8% the vehicle speed dropped to below 10 km/h for a number of vehicles, with one vehicle speed dropping to below 2 km/h. At the very low speed, maintaining balance on the e-scooter was a challenge.

The higher performance vehicles saw a drop in speed to 17 km/h. The test-rider perceived this as safe, and the electrically assisted pedal cycle (EAPC), limited to 250 W continuous power, used by the support rider was able to comfortably keep up in ECO mode.

The hill climb performance of a number of the e-scooters was subjectively rated as poor, with one as very poor.

8.8.3 *Other observations from vehicle testing*

Beyond acceleration and hill climbing, other subjective observations were made regarding the controls and controllability of the vehicles.

None of the scooters tested during the flat acceleration tests exceeded a speed of 25 km/h, which demonstrates that all nine scooters assessed had speed limiting functionality systems. Two of the scooters tested, Scooter E and Scooter H, did not exceed a speed of 20 km/h. In some vehicles there was capability to automatically limit speed while descending by applying a negative, regenerative torque to the motor. Others were able to travel faster downhill than their limited speed on the flat (where they are solely motor propelled without the assistance of gravity).

Several of the vehicles had thumb controls with poor ergonomic design and/or lack of torque demand filtering that meant that vibrations from the road surface would cause the rider to vary the position of the accelerator. This resulted in poor speed modulation, particularly when trying to maintain a lower speed (not at maximum speed where the control is pushed against its end-stop). This was perceived to be caused by having the thumb control a greater distance from the handlebar grip.

One of the vehicles (Scooter E) used a unique propulsion control method of pushing the bars away to accelerate and pulling them close to decelerate, rather than conventional accelerator thumb or twist controls and brake levers. This was hard to control, and awkward to maintain an acceleration demand or set speed. The test rider was unwilling to ride this vehicle downhill.

A combination of small wheels, front wheel drive, solid tyres and poor torque control meant that one of the vehicles (Scooter B) often lost traction of the front wheel. This resulted in the test rider having to put a foot down to avoid falling on more than one occasion. This vehicle also used an electronic (regenerative) brake control that was very hard to modulate, combined with a rear manual foot friction brake that did not provide adequate braking torque to stop, or sufficient ability to modulate braking to control speed. The test rider was unwilling to ride this vehicle downhill.

Vehicles with a mechanical brake (drum, rim or disc) on the front wheel, combined with regenerative braking or a foot friction brake on the rear wheel were easy to modulate and control speed when descending and bringing the vehicle to a stop.

The three-wheeled Scooter G (two wheels at the front, one at the rear) had noticeably lower acceleration and hill climbing performance than the similar two-wheeled version (Scooter H). Discussion with the supplier of this vehicle revealed that while the hardware was the same, it was running different software.

The three-wheeled e-scooter was challenging to manoeuvre at low speed both when riding the vehicle and when pushing it around due to large mass and unusual lean dynamics. This may be due to the test rider’s unfamiliarity with three-wheeled vehicles compared with two-wheeled vehicles.

The three-wheeled vehicle also had a unique disadvantage of not being able to avoid certain features on the road. A pothole, stone or narrow gap between speed bumps is easily avoided on two-wheelers with a single track, but the same features were often hit and ridden over/through on the three-wheeler causing mild concern.

A range of wheel sizes were tested as part of this test and surprisingly the vehicle with a wheel size considerably larger than the other (Scooter I with 16 ” bicycle wheels) did not inspire confidence when riding. The larger wheels are combined with a long wheelbase and long footplate which should also help with stability. Possible reasons for this include a narrow footplate, the motor and battery mass both over the front wheel and geometry such as head angle or rake, but these were not explored further. It may also be because the Scooter I is designed as a manual kit scooter, rather than a ground up e-scooter, requiring stability for a different propulsion mode. The smaller wheeled Scooter F (with 10 ” wheels) was tested immediately after Scooter I and was perceived to have noticeably more stable and confidence inspiring handling.

8.9 Recommendations

8.9.1 Acceleration

An acceleration limit is a good approach to separating the limit of hill climbing capability and the acceleration capability of the vehicle. Our primary recommendation is that limiting the acceleration of an e-scooter is a more effective safety critical measure than implementing an arbitrary power limit.

The range of e-scooters tested were either under or very close to the acceleration limit of 2 m/s^2 defined in BS EN17128:2020. The standard does not specify a rider mass for the test so it must be assumed that the limit must apply to the vehicle regardless of rider mass. The acceleration levels of the e-scooters tested were limited by the maximum torque at the speed of the motor, for a given mass of rider. Therefore, for a lower mass of rider, higher accelerations would likely be achieved. In order for a power-derived acceleration limit to work universally across all masses of e-scooter riders this test would need to be performed at the minimum possible mass of the complete system (e-scooter plus rider). As minimum rider masses are not defined by manufacturers or elsewhere an assumption would need to be made. The problem with this method is that most riders are not the minimum mass, and acceleration will decrease proportionally with the mass of the rider (as the rider makes up the majority of the mass of the system - very different to a car or motorcycle), and so e-scooters with heavier riders will have significantly decreased acceleration and hill climbing performance.

Alternatively, an average rider mass (78.5 kg for the UK population) could be used, but this would result in lighter riders achieving higher rates of acceleration.

The method also does not take into account any influence of wind conditions, and more significantly, gradient.

A true acceleration limit would need to measure the rate of change of speed of the motor, and reduce the torque when a higher rate of change of speed is detected that would exceed the vehicle 2 m/s^2 acceleration limit. This method is not affected by the mass it is accelerating. While this is technically possible, and is used for some torque delivery and traction control systems in automotive applications, the hardware and software capability required is generally not present on e-scooters.

8.9.2 Power

With an acceleration limit, combined with speed limiting functionality engineered into the vehicle along with vehicle mass limits, a power limit does not provide much additional value.

Current power rating test methods defined in UN ECE Regulation No 85 are open to inconsistent and misleading interpretation of manufacturers to achieve desired continuous power rating values.

Continuous power ratings have historically been useful for limiting power on internal combustion engine motorcycles which had similar peak and continuous power values. These limits worked well to limit acceleration to safe levels. Using the same continuous power limits on vehicles powered by electric machines is less useful due to the variation between continuous and peak power measurements.

If the reason for power limits is to prevent unsafe operation of vehicles, in particular short bursts of excessive acceleration (generally not lasting for more than a few seconds), then peak power is more representative of vehicle acceleration duty cycles (over a few seconds) than continuous power (30 minutes).

The other reason for power limits is to limit excessive speed. This is not relevant for e-scooters as speed limiters are commonly used and work better in a range of conditions compared with limiting speed through use of a power limit.

In summary:

Continuous and peak power ratings

- Maximum continuous rated power is not representative of any safety critical performance attribute of a vehicle. Limiting continuous rated power only limits the duration a vehicle can sustain a high output power, the real-world application of this for M- and L-category vehicles are long sustained gradients (mountain passes such as the Grossglockner pass in Europe or Davis Dam in US are often used for automotive testing) or sustained high speed (autobahn).

- For urban mobility, there are no 30-minute long hill climbs or sustained high speed requirements.
- The safety critical vehicle performance attributes that are useful to limit are peak speed and acceleration. Typically electric vehicles may accelerate (at their peak) for 10 seconds (less for urban mobility) – peak power is more representative of this.

UNECE Regulation 85 test

- The current test for “continuous rated power” does not test the maximum power of a motor, but determines that a motor can run at the set power for a set duration without heating up (which any motor with a higher continuous rated power would also be able to do). When used as intended, “continuous rated power” is a metric that is intended to ensure that a motor can operate reliably at the power value specified by the manufacturer and does not place a cap on the maximum performance of a machine, as is the intention when a “maximum rated power” value is specified in regulation.
- The test only works in practice if it is in the interest of the manufacturer to achieve the highest possible value (higher power vehicles are normally more desirable when there isn’t a continuous rated power limit to meet).

It is recognised, that an upper category power limit may help define the boundary with L1e-A category vehicles as well as limit the potential impact of any software-based tampering. So, while no power limit is defined in BS EN17128:2020, an upper power limit could be considered based on a peak power measurement, more relevant for acceleration capability, rather than a continuous rated power measurement (typical of existing standards – which is better suited to identifying minimum performance thresholds). If a peak power limit is to be set it should still allow an e-scooter, with total permissible laden mass, to travel up typical inclines found in UK cities at a speed of at least 10 km/h. Further work would be required to define this peak power value. This could be based on a peak motor output power (tested on motor dyno), a vehicle wheel peak output power (tested on vehicle dyno) or a maximum electrical power input to the motor (maximum battery voltage with peak inverter current).

Calculated vehicle performance related to peak power ratings, along with sustained power ratings for urban hill climbing, is shown in Table 16 and Tables 17a-f for the following vehicle laden mass examples: 60 kg (lightweight e-scooter with light rider), 150 kg (typical shared e-scooter with typical maximum permissible rider mass) and 300 kg (class 3 mobility scooter with heavier rider).

Table 16: Approximate power requirements for performance over mass range

Total Mass	60kg	150kg	300kg
Peak power to achieve 2 m/s^2 @ 10 km/h (W)	400	1000	1900
Peak gradeability (10 km/h) at 2 m/s^2 power (%)	12.0	12.3	11.7
Power to sustain 10 km/h on 8 % grade (W)	275	670	1320

Table 17a: Range of power ratings applied to 60kg light e-scooter with light rider

Peak power	400 W	1000 W	1900 W	Target W
Peak acceleration @ 10 km/h (m/s^2)	2.0	5.3	9.8	2.0 (max)
Peak gradeability @ 10 km/h (%)	12.0	32.7	>100	-

Table 17b: Range of power ratings applied to 60kg light e-scooter with light rider

Sustained power	275 W	670 W	1320 W	Target
Sustained gradeability @ 10 km/h (%)	8.0	21.0	45.8	8.0 (min)

Table 17c: Range of power ratings applied to 150kg typical shared e-scooter with typical maximum permissible rider mass

Peak power	400 W	1000 W	1900 W	Target
Peak acceleration @ 10 km/h (m/s^2)	0.8	2.0	4.0	2.0 (max)
Peak gradeability @ 10 km/h (%)	4.6	8.0	24.3	-

Table 17d: Range of power ratings applied to 150kg typical shared e-scooter with typical maximum permissible rider mass

Sustained power	275 W	670 W	1320 W	Target
Sustained gradeability @ 10 km/h (%)	3.0	8.0	16.5	8.0 (min)

Table 17e Range of power ratings applied to 300kg class 3 mobility scooter with heavier rider

Peak power	400 W	1000 W	1900 W	Target
Peak acceleration @ 10 km/h (m/s^2)	0.4	1.0	2.0	2.0 (max)
Peak gradeability @ 10 km/h (%)	2.1	5.9	11.7	-

Table 17f: Range of power ratings applied to 300kg class 3 mobility scooter with heavier rider

Sustained power	275 W	670 W	1320 W	Target
Sustained gradeability @ 10 km/h (%)	1.3	3.9	8.0	8.0 (min)

8.9.3 Acceleration rate (jerk)

For safe and smooth operation of the vehicle, the rate of change of acceleration rate should be limited. This is described subjectively in BS EN17128:2020 as “smooth and without shock… in order to avoid unstable riding conditions”. An objective test method with criteria would help to guide manufacturers on appropriate acceleration rise rate, and the associated motor torque rise rates that control it.

8.9.4 Acceleration user controls

The acceleration user control (twist throttle or thumb control) had a significant effect on how accurately and repeatedly acceleration could be demanded by the rider, to perform manoeuvres in different conditions.

From a hardware and software perspective, minimum performance levels could help manufacturers provide acceleration controls with appropriate type, geometry, position, force, travel, sensitivity and filtering. This could be implemented via selectable drive modes that alter the acceleration characteristics of the vehicle (such as ‘Comfort’, ‘Eco’ and ‘Sport’) in a similar way to the automotive industry.

8.9.5 Higher performance e-scooters

While a range of e-scooters with claimed power ratings of between 250 and 500 W continuous were tested, these do not represent some of the higher performance models available to buy in the UK with power claims from 1 kW, and some claiming up to 5.4 kW (Table 4). 4 kW is the maximum continuous rated power of L1e-B electric mopeds.

Examples of these higher performance vehicles were not available for the testing, and the test facility, insurance and license level of the test rider may not have been appropriate for the testing of these vehicles, with their higher speeds and acceleration levels.

To perform testing of these vehicles an alternative test location would be required, and an appropriate risk assessment made to account for their performance being more equivalent to motorcycles.

9 Battery safety

9.1 Introduction

This chapter addresses the safety of rechargeable batteries in e-scooters, with particular focus on the following areas:

- Evaluation of the current battery safety and fire risk posed by e-scooters.
- Evaluation of whether these risks increase while charging the battery.
- Investigation into whether the existing safety requirements, under the Supply of Machinery (Safety) Regulons 2008, are suitable for e-scooters.
- Consideration of whether new technical requirements for battery safety should be included in future e-scooter regulations.

This report draws on more than a decade of expertise developed at the University of Warwick on the safety of Li-Ion batteries, and the design and testing standards and legislation applicable to their use across multiple market sectors

9.2 Background on e-scooter batteries

E-scooters are part of an e-mobility revolution which has been enabled by the emergence of mass-produced, affordable Lithium-Ion Batteries (LIBs). Compared to previous battery technologies such as lead-acid (PbA), Nickel-Cadmium (NiCad) and Nickel Metal-Hydride (NiMH), the benefits of LIBs are higher gravimetric and volumetric energy-density and power-density. This means that, within a given mass and physical volume constraint for the battery, a LIB will be capable of delivering higher power and greater energy. Power translates to vehicle performance (acceleration, ascending gradients, top speed) and energy translates to driving/riding range.

As with other types of battery, a LIB comprises several individual Lithium-Ion cells. A single electrochemical cell comprises a cathode (positive electrode) and an anode (negative electrode), kept apart by a separator (a thin, porous membrane, which is an electrical insulator), suffused with an electrolyte which allows the Lithium ions to move freely from anode to cathode (during discharge) and vice versa (during charge). All of these are contained within a cell casing.

In most e-scooter batteries, the cells are cylindrical. Typically, they are the "18650" size, which has an 18mm diameter and 65mm length. Each cell contains around 6-12 Wh of energy when fully charged. An e-scooter battery typically requires 200-500 Wh of energy in total, so it comprises many individual cells.

The term LIB covers several different chemistries, most of which use an anode that is predominantly graphite, but each chemistry has a different cathode material. Examples of cathode materials are:

- Nickel-Manganese-Cobalt Oxide (NMC)
- Nickel-Cobalt-Aluminium Oxide (NCA)
- Lithium Iron Phosphate (LFP)

Each chemistry has pros and cons. NMC and NCA are commonly used in electric vehicles, including e-scooters, because they offer high energy density (good range). LFP inherently has lower energy density, but is also cheaper (per unit of energy) and generally regarded as safer.

9.3 Fire safety risk of e-scooter batteries

9.3.1 Overview of Lithium-Ion Battery fire risks

Despite the advantages of high energy and power, LIBs also have downsides. They are potentially hazardous because they store a large amount of electrochemical energy and, if they are mistreated or contain certain flaws, can undergo a failure mode called thermal runaway, a highly exothermic, extremely rapid chemical reaction which creates harmful gases, flames and other ejecta that can exceed 1000 °C.

LIB fires are extremely difficult to extinguish. Most LIB fires persist until the combustible material within the LIB is consumed. The ferocity of the flames and other ejected material often cause nearby combustible objects to burn, exacerbating the property damage and danger to life.

The electrolyte in Li-Ion cells is almost always an organic carbonate liquid, with lithium hexafluorophosphate dissolved in it, and is highly flammable.

The metal-oxide cathode chemistries (NMC, NCA) have the highest heat release during thermal runaway, and the decomposition of the cathode material creates oxygen, which can enable burning to continue, even when the fire is starved of atmospheric oxygen, for example by using common fire extinguishers or fire blankets.

Thermal runaway starts in a single cell, but in a multi-cell battery such as an e-scooter battery, a chain-reaction can cause some or all of the other cells to undergo thermal runaway, a process known as thermal propagation.

Not all LIBs represent the same level of hazard:

- Some LIB chemistries, such as Lithium Iron Phosphate (LFP) have significantly lower severity and likelihood of thermal runaway, but with a significant deficit in energy and hence vehicle range, compared to metal-oxide chemistries such as NMC.
- Some cells feature safety devices and materials which reduce the likelihood of thermal runaway, particularly to protect against external abuse such as over-charge or short-circuit.
- Some battery management systems actively protect the cells against charge, discharge and temperature conditions outside of the acceptable operating range.
- Some battery management systems communicate electronically with the connected charger, to ensure that the charger always respects the limits of the cells in the battery, even taking account of gradual degradation with ageing of the battery.

- The quality of manufacturing is vital to ensure that inherent flaws, which could lead to thermal runaway, are statistically reduced to a minimum, thereby reducing the likelihood of thermal runaway. However, the risk of manufacturing flaws cannot be completely eliminated with existing technology.
- Some LIBs contain design features or materials to slow or prevent thermal propagation from one cell to the next, thereby limiting the rate and total quantity of heat, toxic gas and other ejecta produced. This reduces the severity of damage and gives people more time and chance to escape harm.

9.3.2 Real-world evidence of e-scooter battery fires

Real-world evidence of e-scooter fires is available from media reports and from safety-focused organisations such as the Electrical Safety First charity. We have also had access to incident reports and data from emergency services organisations, such as the London Fire Brigade. The real-world data clearly show that the overwhelming majority of serious e-scooter fires (those which result in harm to human life and/or severe property damage) have occurred indoors when the e-scooter and/or its battery are being stored or charged. Many of these incidents occurred in dwellings such as flats, while others occurred in commercial properties such as e-bike/e-scooter retail or repair shops.

According to London Fire Brigade, there were 85 reported thermal incidents involving e-scooters between 2017 and 2022, with 30 reported in 2021 and 29 in 2022. Lower numbers in earlier years may be due to lower numbers of e-scooters in use.

Incident reports and anecdotal evidence shows that the ferocity of the fires can produce sufficient harmful gas and heat to cause serious injury or death. In many cases, the only exit route from an enclosed space is blocked by the fire and fumes, trapping people in the enclosed space.

9.3.3 Reasons for severity of e-scooter battery fires

Thermal events in e-scooter batteries cause particularly severe outcomes because:

- They are amongst the largest LIBs in consumer products that are charged in an indoor domestic setting, so contain high quantities of electrochemical energy.
- Thermal runaway of one cell often propagates rapidly to all the other cells, releasing a large amount of energy and toxic gas very rapidly.

The severity of thermal runaway, and the likelihood of it happening, are both greatest when the battery is fully charged, or close to fully charged. This has been shown many times in the scientific literature, for example by Ohneseit et al (2023). The severity and likelihood of thermal runaway are even greater if the LIB is over-charged. Unlike some other types of battery, such as lead-acid, LIBs are not tolerant to over-charging, which is likely to lead to thermal runaway.

E-scooter batteries are often charged in indoor domestic locations and may be left fully charged until they are next used. This means that the e-scooter owner may, unwittingly, leave their e-scooter battery for extended periods, in their home, in the state which represents the greatest potential severity, if the battery goes into thermal runaway, and the greatest likelihood of that happening. This is not misuse by the owner, and it is not reasonable to expect the owner to avoid this pattern of usage. However, it does help to explain why, when e-scooter battery fires occur, they are of such high severity.

9.3.4 Types of abuse which lead to e-scooter battery thermal runaway

In laboratory conditions, thermal runaway can be initiated in LIBs in one of three ways:

- Mechanical abuse, such as crush or nail-penetration.
- Electrical abuse, such as over-charge.
- Thermal abuse, involving the use of a heat source to over-heat the LIB.

Similar initiation methods can occur in the real world. For example:

- Mechanical abuse can occur from cell damage during manufacture or assembly, or as a result of an impact to the battery while riding or from dropping the battery.
- Electrical abuse can occur due to an inadequate Battery Management System (BMS) which does not prevent over-charge, or as a result of a short-circuit at cell or pack level. Short circuits can occur as a result of corrosion following moisture ingress, or damage from excessive vibration.
- Thermal abuse can occur due to inadequate cooling, or due to an unintended heat-source such as electrical arcing or over-heating in components close to the cell. This could be caused, for example, by a short-circuit current in a neighbouring component.

In addition, thermal runaway can occur because of abnormalities inside a LIB cell: a manufacturing fault, such as contamination, can lead to an internal short-circuit; or progressive chemical changes within the cell, particularly lithium plating on the anode, can lead to an internal short-circuit. This can occur, for example, during charging at cold temperatures. In either case, the internal short-circuit generates heat, which in turn leads to thermal runaway.

In e-scooters, the most likely causes of such abuse are:

- Mechanical damage to the battery resulting from impact of the underside of the e-scooter with a kerb or similar hard surface. Many e-scooters have the battery located under the footplate, only a short distance above the ground, with little mechanical protection from the chassis.
- Electrical abuse of the battery, due to incorrect or poorly controlled charging.

As part of this project, we have received feedback from e-scooter manufacturers confirming that mechanical damage to the underside of the e-scooter chassis is relatively common, although there is no direct evidence that this has led to thermal runaway of a battery.

Incorrect or poorly controlled charging can happen in two main ways:

- The wrong charger is used to charge the battery.
- The combination of the battery management system (BMS) and charger provide inadequate means to protect against over-current and/or over-voltage.

Typically, e-scooters are supplied with a charger. The plugs and sockets used to connect the charger to the e-scooter battery are normally of a non-proprietary type, meaning that the same connector type is likely to be used by other chargers with different specifications. If an owner has several chargers for different devices, this presents the risk that an incorrect charger could be connected to the battery. Furthermore, “universal” chargers are widely available from online marketplaces. These are supplied with multiple interchangeable connectors, but electrical compatibility with the battery is the responsibility of the purchaser.

Increasing peak or continuous rated power of motors on the discharge side of batteries will result in increased heat generation of components in the battery pack and BMS. If battery packs (including the BMS components, cells, busbars, other connections and packaging), are engineered appropriately for a higher power, then this is not a safety issue as temperatures will stay within design limits. However, if the pack is not uprated for higher discharge powers, then there is potential that cells will age faster, MOSFETs (Metal Oxide Semiconductor Field Effect Transistors) may get hotter and pack temperatures may be higher when the vehicle is subsequently connected to a charger, which may increase the risk when charging. Components within the battery pack will have specific safe limits for power, voltage, current and/or temperature, that must not be exceeded.

9.3.5 The role of the Battery Management System (BMS)

In our view, the BMS has the primary responsibility for protecting the cells and other components in the battery; even if the wrong charger is attached to the battery, the BMS should be able to protect the battery from potential damage. In general, it does this by measuring the charging voltage and current, comparing those values to the limits of the cells and other components and, if necessary, acting to limit or completely stop the current from flowing.

In batteries with non-hazardous voltage (< 60 Vdc), the BMS limits or stops the current using MOSFETs (Metal Oxide Semiconductor Field Effect Transistors). A MOSFET is a solid-state switch, controlled by the BMS. If the switch is closed, the current flows, and if the switch is open, it does not. In some cases, the BMS will switch the MOSFET on and off at high frequency (many times per second), allowing the BMS to control the current to a level that the BMS deems safe.

However, if the MOSFET is the only protection mechanism, then a single-point failure could allow electrical abuse to occur. This single-point failure could be anywhere in the BMS system, such as the voltage sensor, current sensor, microprocessor hardware, software or the MOSFET itself.

In our view, because of the severity of the potential failure modes of batteries, a protection system that is rendered ineffective by a single-point failure is inadequate; the battery should include redundant protection mechanisms against reasonably foreseeable electrical abuse. Examples of redundant safety mechanisms include:

- A fuse (to protect against over-current).
- An over-voltage protection circuit, e.g. a combination of a fuse and Zener diode.
- A second, separately controlled MOSFET, in series with the first MOSFET.

The safety of automatic functions to achieve safety goals is known as “Functional Safety”. It is an important subject, used widely across multiple industries. Functional Safety standards define a methodology based on the severity and likelihood of hazards, to define the reliability and/or redundancy required to meet safety goals. EN 17128:2020, the standard to e-scooters, does not mention functional safety, whereas the e-bike standard EN 15194:2017 and its normative battery standard EN 50604 both refer normatively to the functional safety standard EN ISO 13849. We recommend that this approach should be adopted for e-scooters.

9.3.6 The role of the charger

Most e-scooter chargers have no communication with the BMS to facilitate closed-loop control of charging. They operate in open-loop, meaning that the charger follows a current and voltage profile which does not vary according to the actual condition of the battery. Typically, the charger follows a constant current – constant voltage (CC-CV) profile. This means it will charge at a constant current until it reaches a pre-define maximum voltage limit and will then gradually reduce the current to maintain that constant voltage until the current drops to a very low pre-defined cut-off level.

The constant current is normally quite low and is generally well within the operating limits of the cells in the battery. The pre-defined maximum voltage is normally set simply as a multiple of the maximum allowable cell voltage. For example, if the maximum cell voltage is 4.2V, and the battery has 10 cells connected in series, then the charger maximum voltage will be set at 4.2x10 = 42V.

The latter assumes that all the cells are perfectly ‘balanced’, meaning that each of the cells connected in series is at the same voltage. However, in a real battery, this is not the case. For various reasons, the cells become imbalanced over time. Some BMS have a balancing circuit, which aims to limit the imbalance, but even with a BMS balancing circuit, there will always be small differences in voltage between series-connected cells.

Because of this, when the charger limits the battery-pack voltage to 42 V, some cells will be somewhat below 4.2 V while others are above 4.2 V, and hence above the cell manufacturer’s limit. With Li-Ion cells any over-voltage has the potential to cause cumulative damage to the cells which may eventually lead to thermal runaway.

Because of this, it is far preferable to have closed-loop control between the BMS and the charger. This allows the BMS to instruct the charger of the maximum voltage allowable that will respect the maximum voltage of all individual cells. To do so, electronic communication between the BMS and the charger is required. This introduces additional components and cost into both the BMS and charger.

In other market sectors, such as automotive, such communication between the BMS and charger is commonplace, and standardised along with the charging plug designs. In the e-scooter (and e-bike) market, however, there is currently no standardisation, despite some serious attempts to define and promote similar standards, notably PD ISO/TS 4210-10:2020 which is a published technical specification but was not ratified as a standard.

9.4 Existing legislation and standards for e-scooter battery safety

9.4.1 Existing legislation

In the Supply of Machinery (Safety) Regulations 2008 (SMSR), Regulation 4(2) provides a definition of machinery to which the regulations apply, and e-scooters meet this definition. They must therefore comply with the relevant Essential Health and Safety Requirements (EHSRs) specified in Schedule 1, Annex 1 of the SMSR. The EHSRs most relevant to e-scooter battery fires are shown in Table 18.

Table 18: Summary of Relevant Health & Safety requirements in the SMSR

Essential Requirements of Directive 2006/42/EC Annex I	Description and Comments
General Principles	Requires the manufacturer to perform a risk assessment (identify hazards, estimate severity, determine mitigations) taking account of foreseeable misuse. Allows for the possibility that the state of the art does not achieve all safety objectives, in which case the aim is to approach these objectives.
1.1.2 Principles of safety integration	Requires safety that encompasses operation, adjustment and maintenance, and the whole foreseeable lifetime of the product, including transport, assembly, disabling and scrapping. Defines a hierarchy of priorities: (1) Eliminate risk; (2) Implement protective measures against risks that cannot be eliminated; (3) Inform users of residual risks. Requires the design and construction to prevent abnormal use which would engender risk.
1.2.1 Safety and reliability of control systems	Requires that a fault in control hardware or software must not lead to a hazardous situation. Reasonably foreseeable human error must not lead to a hazardous situation.
1.3.2 Risk of break-up during operation	If a risk of rupture or disintegration exists, parts concerned must be contained to prevent hazards.
1.3.3 Risk due to falling or ejected objects	Precautions must be taken to prevent risks from falling or ejected objects.
1.5.1 Electricity supply	Requires electrical risks to be prevented.
1.5.5 Extreme Temperatures	Requires steps to be taken to eliminate risk from contact with very hot / very cold parts / materials.
1.5.6 Fire	Requires avoidance of the risk of fire or overheating posed by gases, liquids, dust, vapours, or other substances produced or used by the machinery.
1.5.7 Explosion	Requires avoidance of the risk of explosion posed by gases, liquids, dust, vapours, or other substances produced or used by the machinery.
1.5.13 Emissions of hazardous materials and substances	Requires avoidance of the risk of inhalation / ingestion / contact with hazardous materials and substances.
1.7.1 Information and warnings on the machinery	Warning labels should use symbols and pictograms where possible.

1.7.2 Warnings of residual risks	Warnings of residual risks must be provided.
1.7.4 Instructions	Instructions must be provided.
3.5.1 Batteries	Electrolyte spillage must not occur in rollover. Must avoid accumulation of vapours.
3.5.2 Fire [extinguishers]	Built-in or easily accessible fire extinguishers to be provided for relevant hazards.

Even though the SMSR pre-dates the recent growth of the market for both e-scooters and e-bikes, and many other modern cordless electrical products with Lithium-Ion batteries, the safety requirements listed above provide good coverage of the hazards associated with the batteries used. In our view, the essential health and safety requirements of the Machinery Regulations do not require any changes regarding mitigation of the risk of e-scooter fires. However, it is clear from the number of real-world incidents (see Section 9.3.2) that some examples of e-scooter products have fallen short of meeting these requirements.

9.4.2 Existing standards

The UK government publishes a list of designated standards for machinery. If a product complies with a designated standard, the manufacturer can claim ‘presumption of conformity’ with the corresponding EHSRs in the SMSR.

The EU/UK standard which applies to e-scooters, BS EN 17128:2020, is not a designated standard, and hence does not confer a presumption of conformity with the relevant EHSRs.

Section 11 of BS EN 17128:2020 concerns the energy storage (battery) within the vehicle. It requires that:

> *“The vehicle as well as the sets of energy storage (i.e. battery) shall be designed and constructed such as to prevent any risk of fire and mechanical deterioration resulting from foreseeable abnormal use. Compliance with this requirement is checked by the test described in 11.2.”*

Section 11.2 requires that the test shall either be conducted according to EN 62133 (all parts) or simply the following four tests:

- Battery terminals are short-circuited using fully charged batteries.
- Motor terminals are short-circuited; all of the controls are in ON position and batteries fully charged.
- The vehicle is operated with the electric motor or drive system locked so as to fully discharge the battery or until the system stops.
- The battery is charged for double the recommended charging period or for 24 h, choosing the longest of these two periods.

Verification: there shall be no visible damage for a), b), c) and d) and no overvoltage for d). During the test, the vehicle and the batteries shall not emit any flames, molten metal or release any toxic or flammable gas in hazardous amounts. Protective enclosures shall show no damage when checked visually.

In our view, the option of using tests (a) to (d) above is entirely inadequate. The option of using EN 62133 is better but falls significantly short of the requirements of the more recent standard EN 50604 for “lithium batteries for light EV (electric vehicle) applications”, which is now required for e-bikes to comply with EN 15194:2017, which is the e-bike equivalent to EN 17128:2020 for e-scooters and other PLEVs.

The areas in which EN 62133 fall short are:

Functional safety:

- No normative references to functional safety standards.
- Functional safety conformity of safety-related components is not required.
- Single-fault testing is only required for external short-circuit, not for other safety tests.

BMS:

- Several requirements have no test defined. For example, it states “The design of batteries shall be such that abnormal temperature-rise conditions are prevented”, but there is no test to verify this.
- Many BMS “requirements” are recommended but are not a hard requirement. For example, it states “Protective circuit components should be added as appropriate and consideration given to the end-device application” where the word “should” implies a recommendation, as opposed to “shall” which implies an obligation.

Abuse tests:

- External short circuit resistance (80 mΩ) is too high. We recommend <20 mΩ
- Cell crush test: There is no post-test observation period. We recommend to adopt the 6-hour observation period used in the similar UN38.3 test for approval of batteries under rules for transport of dangerous goods.
- Forced discharge test: Insufficiently rigorous pass criteria. We recommend to adopt the 7-day observation period from UN38.3.

Battery pack tests absent from the standard:

- Thermal cycling
- Water immersion
- Over-discharge
- Deep discharge protection
- Imbalanced charging
- Over-temperature
- Low temperature charging protection

Because of these shortcomings, in our view compliance with EN 62133, and hence EN 17128:2020, does not demonstrate that a battery meets the EHSRs of the SMSR.

On 10 July 2023, the European Council of the European Union adopted a new regulation on batteries and waste batteries. The new regulation 2023/1542has now been published in its final form, and came into force on 17 August 2023.

The regulation will apply to all manufacturers, producers, importers and distributors of every type of battery placed within the EU market (defined as "Economic Operators").

The regulation will apply to all batteries including portable batteries; starting, lightning and ignition (SLI) batteries (used mostly for vehicles and machinery); electric vehicle batteries; industrial; and batteries for light means of transport (LMT, e.g. electric bikes, e-mopeds, e-scooters). The LMT category therefore includes the PLEVs which are the subject of this report, and batteries for L-category type-approved electric vehicles, up to a battery mass limit of 25 kg.

The EU Battery Regulation mentions safety over one hundred times, but in general it contains few specific safety requirements. Chapter 2 is titled “Sustainability and Safety Requirements”, but it only contains safety requirements for stationary battery energy storage systems, not for other battery categories including LMTs.

For stationary battery energy storage systems, Annex V contains a list of tests:

- Thermal shock and cycling
- External short circuit protection
- Overcharge protection
- Over-discharge protection
- Over-temperature protection
- Thermal propagation protection
- Mechanical damage by external forces
- Internal short circuit
- Thermal abuse
- Fire exposure
- Emission of gases

These test categories are very similar to the categories covered in separate legislation and standards for other categories of battery-powered products, including PLEVs (see Section 6 of this report). However, Annex V does not state test methods or pass/fail criteria, but only explains the relevance of these test categories.

In our view, it would not be surprising if a future amendment of the EU Battery Regulation were to expand the applicability of Annex V to other battery categories including LMT batteries. However, in its current form, the regulation simply states in Article 5 that batteries in general “shall not present a risk to human health, to the safety of persons, to property or to the environment”. This is similar to the broad requirement that already exists for all products covered by the UK General Product Safety Regulations 2005, but does not provide the granularity on specific safety requirements that exists in the UK Supply of Machinery (Safety) Regulations 2008.

We assume that secondary legislation and standards will be created in the future to provide greater clarity on how the high-level safety objectives of the EU Battery Regulation should be met.

9.5 Recommendations for future legislation and standards

The Essential Health and Safety Requirements (EHSRs) in the Supply of Machinery (Safety) Regulations 2008 (SMSR) provide adequate coverage of the safety risks associated with Lithium-Ion batteries. However, for e-scooters and their batteries and chargers, there is no designated standard under the SMSR and the existing EU/UK standard, EN 17128:2020, is inadequate and does not provide sufficient coverage to demonstrate compliance with the EHSRs in the SMSR.

The equivalent standard for e-bikes, EN 15194:2017 was updated in August 2023. Previously, the battery requirements in EN 15194:2017 were similar to those in EN 17128:2020. However, with the recent update, EN 15194:2017 requires the e-bike battery to comply with EN 50604-1:2016+A1:2021.

As a result of this recent change, a restriction on the “presumption of conformity” with the EHSRs of the SMSR, for EN 15194:2017 regarding fire explosion and high-temperature hazards, has been removed in the latest list of standards designated under the SMSR.

Section 1 of EN 50604-1 defines the scope of the standard. It states:

> *“This European Standard specifies test procedures and provides acceptable safety requirements for voltage class A and voltage class B removable lithium-ion battery (packs and) systems, to be used as traction batteries of or for electrically propelled* ***road vehicles****. This European Standard is related to the testing of safety performance of battery packs and systems for their intended use for a vehicle.”*

Taking a literal interpretation of this scope, the standard is not applicable to non-road-legal vehicles such as e-scooters. However, in our view, all of the requirements in EN 50604-1 should be applied to the batteries of e-scooters, because the hazards are essentially the same as for road-legal e-mobility vehicles with removable lithium-ion batteries. If e-scooters were made legal for road-use, then the existing scope of EN 50604-1 would be appropriate.

EN 50604-1 is the most complete and robust EU/UK standard applicable to light electric vehicle batteries. However, it also has some significant shortcomings. Our recommendations for updates to EN 50604-1 are summarised below:

1. EN 50604-1 should undergo a thorough revision following a review of errors and inconsistencies in the current version. For example, it refers normatively to other standards which have been withdrawn, or sections of other standards which do not exist.
2. EN 50604-1 should be updated to include requirements for production quality of the cells and the battery pack.
3. EN 50604-1 should be updated to include creepage and clearance distances.
4. The deep-discharge test in EN 50604-1 should be reviewed and updated, and a rationale should be provided.

5. EN 50604-1 should be updated to include an imbalanced charging test.
6. A thermal propagation requirement, similar to that in GTR20 / UNECE Reg100.03 should be considered for e-scooter batteries. However, the pass/fail criteria should be decided based on the hazards of thermal propagation in an indoor domestic setting.
7. EN 50604-1 should be updated to include a charging over-current test.

We recommend that EN 17128:2020 should be updated to have the same requirement as EN 15194:2017 regarding the battery – specifically, that the battery must comply with EN 50604-1:2016+A1:2021.

10 Sustainability of e-scooters

10.1 Introduction

In the face of climate change, the UK's transport sector remains a critical area for emission reductions, accounting for 24 % of the nation's total emissions in 2020, predominantly from cars and taxis (DfT, 2022). The emerging micromobility landscape, featuring e-scooters as a prominent solution, presents an opportunity to address these concerns. Following regulatory trials beginning in July 2020 (GOV.UK, n.d.), shared electric scooters (e-scooters) have seen rapid adoption, with participants and rides reaching millions, reflecting a significant shift in urban transportation dynamics.

Data from Transport for London indicates significant growth in e-scooter trials, with ten boroughs participating, over 600 parking spots, and a fleet exceeding 5,000 e-scooters, cumulatively facilitating over 2.5 million trips and spanning 6.46 million kilometres (Hubbard, 2023). The private e-scooter market is also robust, with estimates suggesting 750,000 units in circulation by the close of 2022, despite the vehicles not being legally permitted on public roads yet (Roberts, 2023).

Discussions about e-scooters frequently focus on their potential to decrease greenhouse gas emissions. Industry benchmarks conducted by Voi indicate that e-scooters produce between 35 to 67 g of CO2e per kilometre, a figure that is lower than that of electric cars and buses (EY, 2020). The report from the International Transport Forum shows that shared new-generation e-scooters are associated with emissions of 100 g per kilometre, while private e-scooters emit 40 g per kilometre (Cazzola and Crist, 2020). To provide a more comprehensive comparison, it's crucial to consider the emissions of internal combustion engine (ICE) vehicles. On average, ICE vehicles emit significantly more CO2e per passenger kilometre compared to e-scooters and electric vehicles. For instance, a typical gasoline-powered car emits about 120 to 180 g of CO2e per kilometre (DESNZ, 2023). Even plug-in hybrid electric vehicles (PHEVs), which are more efficient, such as a model from Vauxhall, emit around 35-55 g CO2e per km (Vauxhall, 2023), which is comparable to or slightly less than some e-scooter emissions. This comparison highlights the environmental benefits of e-scooters (from a 'tailpipe' emissions perspective), when considering that ICE vehicles' emissions are typically higher. However, the lifespan of the vehicle and emissions generated during the manufacturing and distribution phases are also important factors to consider.

Several academic studies have applied a life cycle assessment (LCA) approach to discern the environmental footprint of e-scooters. Hollingsworth et al. (2019) evaluated the dockless, shared, e-scooters in the city of Raleigh, North Carolina, USA, estimating a lifespan of 0.5–2 years. This study shows that emissions from an e-scooter range from 94 to 305 g CO2/km, in which 50 % of total impacts are due to its production and 43% result from the collection and distribution process. Chester (2019) calculated the emissions for the complete life cycle of an e-scooter in the USA, with results varying (between 200 to 400 g CO2/km) based on the logistics of the collection and distribution processes. Within Europe, Voi's LCA of its e-scooters showed emissions of 35 g CO2e/km, justifying such a low number with the electrification of vehicles used in the collection/distribution, to the use of replaceable batteries and of renewable energies for battery charging, as well as to recycling of materials (EY, 2020).

Despite the growing prevalence of private e-scooters, as indicated by market data and user trends, there remains a dearth of detailed environmental impact assessments for these personal mobility devices. This lack of targeted LCA studies on private e-scooters represents a critical knowledge gap, especially given their distinct usage patterns, maintenance practices, and life spans compared to their shared counterparts. Understanding the full environmental implications of this increasingly popular mode of transport is essential for informed policy-making and sustainable urban mobility planning.

In examining current LCA studies for e-scooters, it's clear that many rely on similar background data to assess environmental impacts. This reliance poses a significant limitation, as it may not adequately reflect the rapid advancements in e-scooter technology and the evolving patterns of use, both vital for a thorough environmental impact evaluation. Furthermore, current environmental impact assessments show a wide range of results, largely due to varying assumptions about the characteristics and service models of e-scooters. This variability underscores the importance of recognising the limitations of these assumptions. Additionally, these studies often do not fully account for local-specific factors, including the distinct approaches to collection, distribution, and recycling practices.

Therefore, a comparative analysis focusing on the environmental impacts and lifecycle 'hotspots' of both shared and private e-scooters, tailored to the UK's specific conditions, is essential. This will not only address ecological issues related to e-scooter usage but also enhance our understanding of the challenges in urban mobility.

This chapter seeks to assess the environmental performance of e-scooter systems, furnishing policymakers with data-driven insights on material consumption and the substitution of traditional transport methods. It evaluates under what circumstances e-scooters may offer an environmental benefit. Through LCA methodologies, the global warming impact of both shared and private e-scooters is quantified, in best- and worst-case scenarios. This analysis aids in pinpointing the key contributors to environmental degradation, thus empowering authorities with informed guidance for policy or procedural improvements to curtail such effects. Additionally, we propose quantified and considered recommendations to move towards the best-case scenario. These recommendations are structured to encourage market-led advancements in sustainability, outlining progressive standards, features, and processes that could shape the future of low-carbon, urban transportation.

10.2 Method

The functional unit for this LCA is defined as 'per e-scooter'. The study uses this unit to calculate and compare the environmental impacts of shared and private e-scooters. Establishing 'per e-scooter' as the functional unit ensures a consistent framework for emissions analysis, allowing for a clear comparison.

The project quantifies the total emissions over the e-scooter's entire lifecycle, covering emissions from material extraction, processing, manufacturing, operation, maintenance, and end-of-life disposal. This total figure represents the complete environmental burden of an e-scooter from inception to disposal.

Subsequently, these total emissions are allocated on a per passenger, per-kilometre basis. This allocation translates the overall environmental impact into emissions per distance travelled, a measure that aligns with the common usage of e-scooters. It provides a relevant metric for consumers to understand the environmental footprint related to the distance travelled on an e-scooter.

By calculating the total emissions first and then breaking them down per kilometre, the study ensures a comprehensive evaluation of the e-scooter's environmental impact, offering an insightful and applicable measure for comparing the sustainability of shared versus private e-scooter use, as well as other transport modes.

10.2.1 Shared e-scooters

10.2.1.1 System boundary

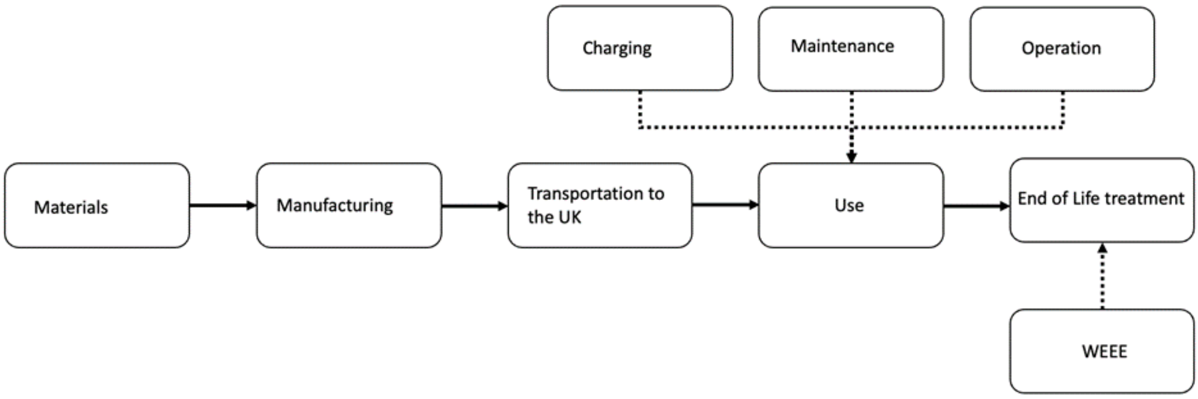

Figure 11 System boundary diagram for the LCA on shared e-scooters in the UK

10.2.1.2 Material

The composition of materials and their respective mass proportions in this study (Table 19) are mainly sourced from various research papers, including studies by Beryl (2023), Hollingsworth et al. (2019), Ishaq et al. (2022), Reis et al. (2023). Considering vehicles operated in the UK by Voi, Lime, TIER and Zwings, the shared e-scooter's mass range is between 27 and 34 kg. Additionally, the emission factors for these materials are obtained from the ecoinvent database, which is a commercial life cycle inventory database.

Table 19: Material composition for shared e-scooters

Material Type	Role	% of Total Mass	Mass (kg)	General Environmental Footprint (kg CO_2e/kg)	E-Scooter Specific Environmental Footprint (kg CO_2e)
Aluminium	Frame and wheels	43.7 %	11.80-14.86	7.59	89.56-112.79
Steel	Screws, washers, frame items, brake disc, etc.	11.2 %	3.02-3.81	1.98	5.98-7.54
Plastics	Splash guard, wheel cover, frame cover, etc.	9.2 %	2.48-3.13	5.66	14.04-17.72
Li-ion	Battery	8.9 %	2.40-3.03	17.86	42.86-54.12
Electric Motor	Propulsion	13.8 %	3.73-4.69	9.30	34.69-43.62
Copper, **Light Emitting Diode (LED),** **Printed Circuit Board**	Cables, LED brake and headlights, Control panel	4.1 %	1.11-1.39	31.96	35.48-44.42
Rubber	Tyres, handle grips, standing mat, etc.	9.1 %	2.46-3.09	2.98	7.33-9.21

10.2.1.3 Transportation

It is presumed that the assembly of the e-scooters is carried out in the Chinese provinces of Jiangsu, Zhejiang, and Guangdong, as these are the locations most frequently cited by a large number of manufacturers. The transportation-related impacts have been determined using the information presented in Table 20.

Table 20: Transportation inventory for shared e-scooters from China to the UK

Transportation Routes	Mode	Travel Distance (km)	Comments	General Environmental Footprint (kg*km)	E-Scooter Specific Environmental Footprint (kg CO2e)
From the Original Equipment Manufacturer to ports in China	Lorry	250	It is assumed that the OEMs are located in sector cluster regions.	0.00019	1.66-1.90
From ports in China to ports in the UK	Sea freight	21694	Utilised an online distance calculator	0.00001	7.59-8.68
From UK ports to regional distribution centres or retail warehouses	Truck	400	The figures suggested by Voi were used (Chaniotakis et al., 2023)	0.00018	2.52-2.88
From regional distribution centres or retail warehouses to the end-use locations	Van	120	Estimation	0.00018	0.76-0.86

10.2.1.4 Use

It's essential to focus on the primary aspects of shared electric scooters' usage phase, which are charging, operation, and maintenance. The key environmental impact factors here include the electricity consumed for charging the scooters, the use of electric vans for their collection and redistribution, and the materials needed for their upkeep. The lifecycle inventory for the usage stage has been formulated through a combination of independent reports, analysis of secondary data, and information supplied by the e-scooter operators. This is detailed in Table 20.

Regarding the lifespan of e-scooters, the analysis often centres on their overall lifecycle distance covered and battery longevity. The total lifecycle energy consumption of shared scooters can differ based on these two metrics.

Shared e-scooters often use swappable batteries to improve charging and servicing operations. This has resulted in shared e-scooters and their associated bank of batteries having different life, use and operational patterns.

The analysis of two years of e-scooter fleet data, provided by the operations team of Voi, offers insightful findings. This data, tracking e-scooters via vehicle identification numbers, encompasses two models: the Voiager 3X (V3X), introduced in 2019, and the Voiager 4 (V4), released in 2021. An estimated lifespan of 55 months (approximately 4.6 years) is projected for e-scooter frames, while e-scooter batteries are expected to last for about 44 months (roughly 3.7 years)(Voi, 2022). From the data Voi provided, it's observed that the average distance covered by each e-scooter across all markets is approximately 4.5 km per day. In terms of overall usage, the 55-month lifespan of an e-scooter frame translates to about 6529 km over its lifetime. Meanwhile, the battery, with a 44-month lifespan, is expected to last for about

5,389 km. This usage pattern indicates that each e-scooter frame necessitates 1.21 batteries throughout its operational life. To calculate the battery lifespan in terms of energy consumption, a rate of 19.19 watthours per km, derived from Voi's data, is applied. This results in a total estimated battery life of 103.4 kWh.

In evaluating the environmental impact of shared e-scooters, it's crucial to consider a range of operational possibilities. This assessment includes two distinct scenarios – the best-case and worst-case – to encapsulate the extremes of what is achievable in terms of mass and range. The best-case scenario represents an ideal blend of lightweight construction and longevity, while the worst-case scenario considers the implications of a heavier build and a shorter range. These contrasting scenarios help in understanding the full spectrum of environmental impacts associated with shared e-scooters. In the UK, the prevalent method for e-scooter collection and redistribution now primarily involves electric vehicles. This shift is indicative of the industry's dedicated progression towards more sustainable practices. Consultations with e-scooter operators in the UK have led to a consensus that the inclusion of emissions from diesel vans in this context would not provide a true representation of the industry's current logistics operations, which are increasingly environmentally conscious.

Best-Case Scenario for Shared E-Scooters: shared e-scooters weigh 27 kg and achieve a 12,000 km, showcasing efficient design and extended lifespan. Using a rate of 19.19 watthours per km to calculate battery lifespan in terms of energy consumption, the total electricity consumption for this scenario is approximately 230.28 kWh.

Worst-Case Scenario for Shared E-Scooters: shared e-scooters have a heavier mass of 34 kg and a reduced range of 6,529 km, indicating higher energy use and a shorter operational life. With the same energy consumption rate of 19.19 watthours per km, the total electricity consumption for this scenario amounts to approximately 125.29 kWh.

The operational environmental impact of shared e-scooters is determined by various factors including the daily travel distance of each scooter, the method and frequency of retrieval for charging, and the timing and location of these charging sessions. The responsibility falls on the operator to collect the scooters from various city locations as soon as they are ready for pickup. This collection process is not based on fixed routes, specific areas, or choosing certain scooters. It is generally assumed that the scooters are gathered every evening using electric vans for charging, regardless of their battery levels.

A study by UCL has found that the average operational distance travelled for each km of e-scooter use is 0.0598 km/km (Chaniotakis et al., 2023). This was determined by analysing Voi’s operational data in the UK. When applying this to the designed scenarios for shared e-scooters, it emerges that for a total lifecycle distance of 6,529 km, the operational distance is 390.43 km, whereas for a lifecycle distance of 12,000 km, it is 717.6 km. Utilising the electricity conversion factors for the average electric van in the UK, which stands at 0.06762 kg CO2e/km (DESNZ, 2023), the estimated carbon footprint for the operation stage of shared e-scooters is thus calculated to be approximately 26.37 kg CO2e for the worst-case scenario, and 48.58 kg CO2e for the best-case scenario.

Table 21: Inventory data of use stage for shared e-scooters

Flows	Amount	General Environmental Footprint	E-Scooter Specific Environmental Footprint (kg CO2e)
Best-case (12000 km) Charging	230.28 kWh	0.207 kg CO2e/kWh	47.67
Best-case (12000 km) Operation	717.6 km	0.06762 kg CO2e/km	48.52
Best case total footprint (kg CO2e)	-	-	96.19
Worst-case (6529 km Charging	125.29 kWh	0.207 kg CO2e/kWh	25.94
Worst-case (6529 km Operation	390.43 km	0.06762 kg CO2e/km	26.40
Worst case total footprint (kg CO2e)	-	-	52.30

Acquiring independent data to assess the environmental impact of maintaining shared e-scooters has been notably challenging. This complexity arises from the varied maintenance protocols across different e-scooter companies. For this study, we've drawn parallels with the automotive industry, using a similar approach based on the weighting ratio of consumables. We have referred to maintenance checklists from several shared e-scooter providers to estimate the consumable materials and their respective mass ratios, as documented in Table 22. Mass values shown are based on the material compositions mass values indicated in Table 19. Information on the general environmental footprint shown in Table 22 was sourced from the commercial life cycle inventory database, ‘ecoinvent’. Values shown for tyres in Table 22 are based on an assumed requirement that tyres need to be replaced every 1500-2500 miles (Levy, 2023).

Regarding the lithium-ion batteries used in shared e-scooters, while they can undergo 400-500 recharge cycles, the average lifespan of an e-scooter battery is projected to be 3-4 years. Contrary to the notion of complete battery replacement, the actual practice involves using swappable batteries. As per Voi's report (Voi, 2022), for every 100 e-scooters, there would be a utilisation of 120 swappable batteries throughout their operational life. This effectively means that each e-scooter utilises only about 20% of an additional battery, rather than a full battery replacement.

This study does not account for the energy consumption associated with maintenance, as it is relatively minimal for routine upkeep of e-scooters.

Table 22: Maintenance inventory for shared e-scooters

Maintenance Consumables	Material Type	Maintenance Ratio /Frequency	Mass (kg)	General Environmental Footprint (kg CO2e/kg)	E-Scooter Specific Environmental Footprint (kg CO2e)
Handlebar grips, brake cables, base trim, etc.	Plastic	20 %	0.50-0.63	5.66	2.83-3.57
Screws, washers, etc.	Steel	10 %	0.30-0.38	1.98	0.59-0.75
Frame, wheels etc.	Aluminium	10 %	1.18-1.49	7.59	8.96-11.31
Tyres	Tyres	2 time replace	4.92-6.18	2.98	14.66-18.42
Battery	Battery	0.2 time replace	0.48-0.61	17.86	8.57-10.89

10.2.1.5 End-of-Life (EoL)

Our investigation and discussions with operators of shared e-scooters indicate that they usually utilise independent recycling services for EoL shared e-scooters. We assume these practices comply with the Waste Electrical and Electronic Equipment (WEEE) Directive, leading to the conclusion that all metal parts of the scooters are fully recycled. In an approach paralleling passenger car disposal, we allocate all environmental impacts from metal parts to the secondary materials derived from the recycling process. Tyres are either repurposed as secondary materials for uses like cement production (50 %) or incinerated in municipal facilities (50 %).

Considering UK regulations on classifying portable and industrial batteries, e-scooter batteries fall under the automotive battery pack category. While the EU's New Batteries Regulation sets targets for recycling lithium-based batteries, aiming for a 51 % collection rate by December 2028 and a 65 % recycling rate by mass, it is crucial to recognise that these figures are aspirational targets rather than current realities. Moreover, post-Brexit, the UK's adoption of these EU targets is not guaranteed. This study references the EU targets as a basis to estimate the potential recyclable mass of EoL e-scooter batteries in an optimal scenario, but it acknowledges that the actual recycling rates are currently unavailable and may vary within the UK.

Currently, the recycling of lithium-ion batteries in the industry typically involves a combination of three main methods: direct physical recycling, pyrometallurgy, and hydrometallurgy. The process often starts with direct physical recycling to extract bulk metals from the casing and other components. Following this, pyrometallurgy is used to remove volatile substances and polymers, resulting in the production of a slag and an alloy. In this stage, while valuable metals like nickel, cobalt, and manganese are recovered, lithium and aluminium are generally lost in the slag, and other components are burned off. Finally, hydrometallurgy is employed to separate the metals contained within the alloy fraction. This comprehensive process is widely commercialised for EoL battery treatment. In this study, this integrated recycling approach is employed as a model to estimate the mass of recyclable EoL e-scooter batteries under an ideal scenario.

In the UK, electric motor recycling falls under WEEE Regulations. Being 100 % recyclable, their valuable components, such as copper windings, are separated and reused. The process includes collecting the motors, dismantling them, and recycling the various components at different facilities.

Table 23 details the specific recycling rates and treatment pathways considered. For all recycled materials, the transport to the recycling facility is accounted for, with an estimated average distance of around 100 km.

Table 23: End of life flows for shared e-scooters

Materials	Material composition	Material Recycled rate	E-scooter Recycling Rate	Mass (kg)	General Environmental Footprint (kg CO2e/kg)	E-Scooter Specific Environmental Footprint (kg CO2e)
Aluminium	40 %	95 %	90 %	9.23-11.63	0.02	0.17-0.22
Steel	14.20 %	95 %	90 %	3.28-4.13	0.01	0.03-0.04
Plastics	9.20 %	75 %	90 %	1.68-2.11	1.60	2.68-3.37
Battery	10.60 %	65 %	90 %	1.67-2.11	0.88	1.47-1.85
Electric Motors	18.90 %	100 %	90 %	4.59-5.78	0.01	0.04-0.05
Electronics	3.60 %	100 %	90 %	0.87-1.10	3.05	2.65-3.36
Rubber	3.50 %	100 %	90 %	0.85-1.07	1.32	1.12-1.41

10.2.1.6 Summary

The life cycle assessment for shared e-scooters in the UK indicates that the carbon emissions vary significantly depending on the operational scenario. In the best-case scenario, characterised by a 27 kg e-scooter lasting 12,000 km, the total carbon emissions are calculated at 366.11 kg CO2e. This scenario includes emissions from materials, use, transportation, and end-of-life considerations.

In the worst-case scenario, with the e-scooter weighing 34 kg and covering only 6,529 km, the total emissions are higher, at 390.72 kg CO2e. The increased emissions in this scenario stem from the same categories, with the difference attributed to the decreased efficiency and increased resource use.

For shared e-scooters, this results in per passenger per km emissions of a worst case of 0.060 kg per km of CO2e and a best case of 0.031 kg per km of CO2e.

These results highlight the importance of e-scooter mass and lifespan in their overall environmental impact, with the best-case scenario demonstrating a more sustainable profile.

Table 24: Comparative LCA emissions of shared e-scooters: best vs. worst-case scenarios

Source of emissions	Shared (worst case)	Shared (best case)	Unit
Materials	289.42	229.94	kg CO2e
Use	97.28	131.80	kg CO2e
Transportation	14.32	12.53	kg CO2e
EoL	-10.3	-8.16	kg CO2e
Total	390.72	366.11	kg CO2e
Per passenger per km	0.060	0.031	kg per km of CO2e

10.2.2 Private e-scooters

10.2.2.1 System boundary

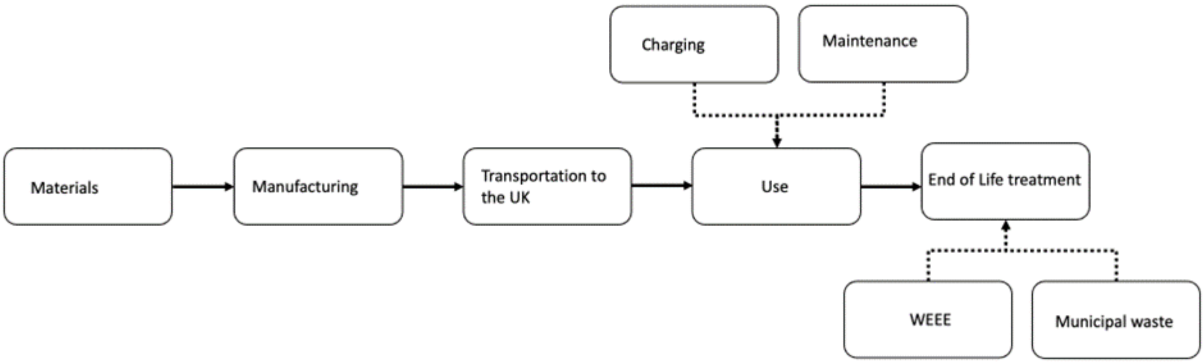

Figure 12 System boundary diagram for the LCA on private e-scooters in the UK

10.2.2.2 Material

The determination of material composition and their respective mass percentages for private e-scooters in this study is based on our own teardown analysis of a Xiaomi 365 Pro e-scooter, supplemented by findings from several studies, including those by Ishaq et al. (2022), Reis et al. (2023), Cazzola and CRIST (2020). Private e-scooters are more variable product-to-product than shared e-scooters with models ranging from low mass and low cost items designed for recreational use, to more durable, premium vehicles designed to handle regular, transportation use. For the purposes of this study, the mass of private e-scooters is estimated to be in the range of 15-20 kg, to meet requirements set out in other areas of this report covering safety and structural integrity. The emission factors for these materials are based on data from the ecoinvent database, a commercial life cycle inventory database.

Table 25: Material composition for private e-scooters

Material Type	Role	% of Total Mass	Mass (kg)	General Environmental Footprint (kg CO2e/kg)	E-Scooter Specific Environmental Footprint (kg CO2e)
Aluminium	Frame and wheels	42.0 %	6.30-8.40	7.59	47.82-63.76
Steel	Screws, washers, frame items, brake disc, etc.	7.0 %	1.05-1.40	1.98	2.08-2.77
Plastics	Splash guard, wheel cover, frame cover, etc.	4.0 %	0.60-0.80	5.66	3.40-4.53
Li-ion Battery	Battery	15.1 %	2.27-3.02	17.86	40.54-53.94
Electric Motor	Propulsion	20.0 %	3.00-4.00	9.30	27.90-37.20
Copper, Light Emitting Diode (LED), Printed Circuit Board	Cables, LED brake and headlights, Control panel	6.9 %	1.04-1.38	31.96	33.24-44.10
Rubber	Tyres, handle grips, standing mat, etc.	5.0 %	0.75-1.00	2.98	2.24-2.98

10.2.2.3 Transportation

The transportation state of private e-scooters is assumed to be identical to that of shared e-scooters (Table 26).

Table 26: Transportation inventory for private e-scooters from China to the UK

Transportation Routes	Mode	Travel Distance (km)	Comments	General Environmental Footprint (kg*km)	E-Scooter Specific Environmental Footprint (kg CO2e)
From the OEM to ports in China	Lorry	250	It is assumed that the OEMs are located in sector cluster regions	0.00019	0.71-0.95
From ports in China to ports in the UK	Sea freight	21694	Utilised an online distance calculator	0.00001	3.25-4.34
From UK ports to regional distribution centres or retail warehouses	Truck	400	The figures suggested by Voi were used (Chaniotakis et al 2023)	0.00018	1.08-1.44
From regional distribution centres or retail warehouses to the end-use locations	Van	120	Estimation	0.00018	0.32-0.43

10.2.2.4 Use

As an emerging transport mode, little data exists on the use of private e-scooters, particularly on their use in the UK. The variability of products on the market suggests that the expected lifespan or total range would have an equally large range, with lower quality products having a life of perhaps only a few hundred km. Higher quality products, when used, serviced and maintained correctly, could have long serviceable lives covering tens of thousands of km. Given this spectrum of potential lifespans, from lower quality e-scooters that last only a few hundred kilometres to high-quality ones capable of tens of thousands of kilometres, it is instructive to consider two distinct scenarios: the worst-case and the best-case. These scenarios help to concretely illustrate the range of possibilities in e-scooter longevity and usage, providing a clearer understanding of their potential impact and utility.

The method used to estimate material usage for maintaining shared e-scooters is adapted for private e-scooters in the best-case scenario, with lower maintenance ratios reflecting their different usage patterns, as detailed in Table 28. In contrast, the worst-case scenario assumes no maintenance for private e-scooters.

Worst-Case Scenario: the lifespan of a private e-scooter is limited to just one year, aligning with the current warranty period and assuming no maintenance. This assumes a usage pattern primarily centred around work commutes on weekdays. With 250 working days in a year, and considering two commutes per day, the e-scooter is used extensively but not excessively. Each commute journey averages 2.2 km, based on the typical length of a shared e-scooter trip. This results in the e-scooter covering a total of approximately 1,100 km over its one-year lifespan. To calculate the battery lifespan in terms of energy consumption for this scenario, a rate of 19.19 watthours per km, derived from Voi's data, is applied, indicating a total energy usage of approximately 21.11 kWh over the private e-scooter's lifespan (Table 27).

Best-Case Scenario: the private e-scooter parallels the longevity and efficiency observed in the best-performing shared e-scooters, assuming regular maintenance. Here, the private e-scooter is envisaged to last 12,000 km. This extended lifespan represents a more optimistic and sustainable use case, where the e-scooter serves its purpose over an extended period, thereby maximising its utility and minimising its environmental footprint. Applying the same rate of 19.19 watthours per km for energy consumption calculation, the total energy usage for this scenario would be approximately 230.3 kWh over the entire lifespan of the private e-scooter (Table 27).

Table 27: Inventory data of use stage for private e-scooters

Scenarios	Flows	Amount (kWh)	General Environmental Footprint (kg CO2e/kWh)	E-Scooter Specific Environmental Footprint (kg CO2e)
Worst-Case (1100 km)	Charging	21.11	0.21	4.37
Best-Case (12000 km)	Charging	230.3	0.21	47.67

Table 28: Maintenance inventory for private e-scooters (only for best-case scenario)

Maintenance Consumables	Material Type	Maintenance Ratio /Frequency	Mass (kg)	General Environmental Footprint (kg CO2e/kg)	E-Scooter Specific Environmental Footprint (kg CO2e)
Handlebar grips, brake cables, base trim, etc.	Plastic	10 %	0.06-0.08	5.66	0.34-0.45
Screws, washers, etc.	Steel	5 %	0.05-0.07	1.98	0.10-0.14
Frame, wheels etc.	Aluminium	5 %	0.32-0.42	7.59	2.43-3.19
Tyres	Tyres	1 time replace	0.75-1.00	2.98	2.24-2.98
Battery	Battery	1 time replace	2.27-3.02	17.86	40.54-53.94

10.2.2.5 End of Life

A hybrid approach is employed for modelling the disposal of EoL private e-scooters: the scooter frames (gliders) are disposed of through household waste collection routes, utilising the corresponding recycling rates from DEFRA , while all electrical and electronic components, as well as tyres, follow the WEEE disposal pathway. UK waste statistics are utilised to model the recycling rates of the scooter frames.

The worst-case scenario (Table 29) uses an e-scooter recycling rate of 31.2 %, this is the UK's rate of recycling and reuse for waste electrical and electronic equipment for 2021. The best case (Table 30) considers a vehicle rate of recycling of 90 %, as used for shared e-scooters.

Table 29: End of life flows for private e-scooters (Worst-Case)

Materials	Material composition	Material Recycled rate	E-scooter Recycling Rate	Mass (kg)	General Environmental Footprint (kg CO2e/kg)	E-Scooter Specific Environmental Footprint (kg CO2e)
Aluminium	42.0 %	95 %	31.2 %	1.87-2.49	0.02	0.04-0.05
Steel	7.0 %	95 %	31.2 %	0.31-0.41	0.01	0.00-0.00
Plastics	4.0 %	75 %	31.2 %	0.14-0.19	1.60	0.22-0.30
Battery	21.0 %	65 %	31.2 %	0.64-0.85	0.88	0.56-0.75
Electric Motors	20.0 %	100 %	31.2 %	0.94-1.25	0.01	0.01-0.01
Electronics	1.0 %	100 %	31.2 %	0.05-0.06	3.05	0.15-0.18
Rubber	5.0 %	100 %	31.2 %	0.23-0.31	1.32	0.30-0.41

Table 30: End of life flows for private e-scooters (Best-Case)

Materials	Material composition	Material Recycled rate	e-scooter Recycling Rate	Mass (kg)	General Environmental Footprint (kg CO2e/kg)	E-Scooter Specific Environmental Footprint (kg CO2e)
Aluminium	42.0 %	95 %	90.0 %	5.39-7.18	0.02	0.10-0.13
Steel	7.0 %	95 %	90.0 %	0.90-1.20	0.01	0.01-0.01
Plastics	4.0 %	75 %	90.0 %	0.41-0.54	1.60	0.65-0.86
Battery	21.0 %	65 %	90.0 %	1.84-2.46	0.88	1.62-2.16
Electric Motors	20.0 %	100 %	90.0 %	2.70-3.60	0.01	0.02-0.03
Electronics	1.0 %	100 %	90.0 %	0.14-0.18	3.05	0.43-0.55
Rubber	5.0 %	100 %	90.0 %	0.68-0.90	1.32	0.90-1.18

10.2.2.6 Summary

The life cycle assessment for private e-scooters in the UK reveals differing carbon emissions between the best and worst-case scenarios. For the best-case scenario, which assumes a private e-scooter with a mass of 15 kg and a lifespan of 12,000 km, the total emissions are 252.17 kg CO2e. This includes material production, operational use, transportation, and end-of-life processing.

Alternatively, the worst-case scenario for private e-scooters, with a 20 kg mass and a total usage of approximately 1,100 km, results in total emissions of 219.11 kg CO2e.

For private e-scooters, this results in per passenger per km emissions of a worst case of 0.199 kg per km of CO2e and a best case of 0.021 kg per km of CO2e.

These findings indicate that the lifetime usage and material efficiency of private e-scooters are crucial factors for their environmental impact, with both scenarios offering insights into the potential for sustainability within personal transport options (Table 31).

Table 31: Comparative LCA emissions of private e-scooters: best vs. worst-case scenarios

Emissions source	Private (best case)	Private (worst case)	Unit
Materials	157.22	209.28	kg CO2e
Use	93.32	4.37	kg CO2e
Transportation	5.36	7.16	kg CO2e
EoL	-3.73	-1.7	kg CO2e
Total	252.17	219.11	kg CO2e
Per passenger per km	0.021	0.199	kg per km of CO2e

10.3 Results

10.3.1 *Overview of life cycle emissions in the best- and worst-case scenarios*

Figure 13 illustrates the total life cycle emissions for both shared and private e-scooters across best and worst-case scenarios. This visual representation reveals a notable trend: the total emissions per private e-scooter are consistently lower than those of shared e-scooters. However, this observation should not be immediately interpreted as private e-scooters being inherently more sustainable. Benefiting from reduced material use and lower operational emissions, private e-scooters show lower total lifecycle emissions. Nevertheless, their usage patterns and intensity vary significantly from shared e-scooters, potentially affecting their emissions per kilometre. Thus, despite private e-scooters appearing more environmentally friendly at first glance due to their lower total emissions, a holistic view that encompasses emissions per kilometre is essential for a thorough sustainability assessment, as detailed in Section 10.3.4

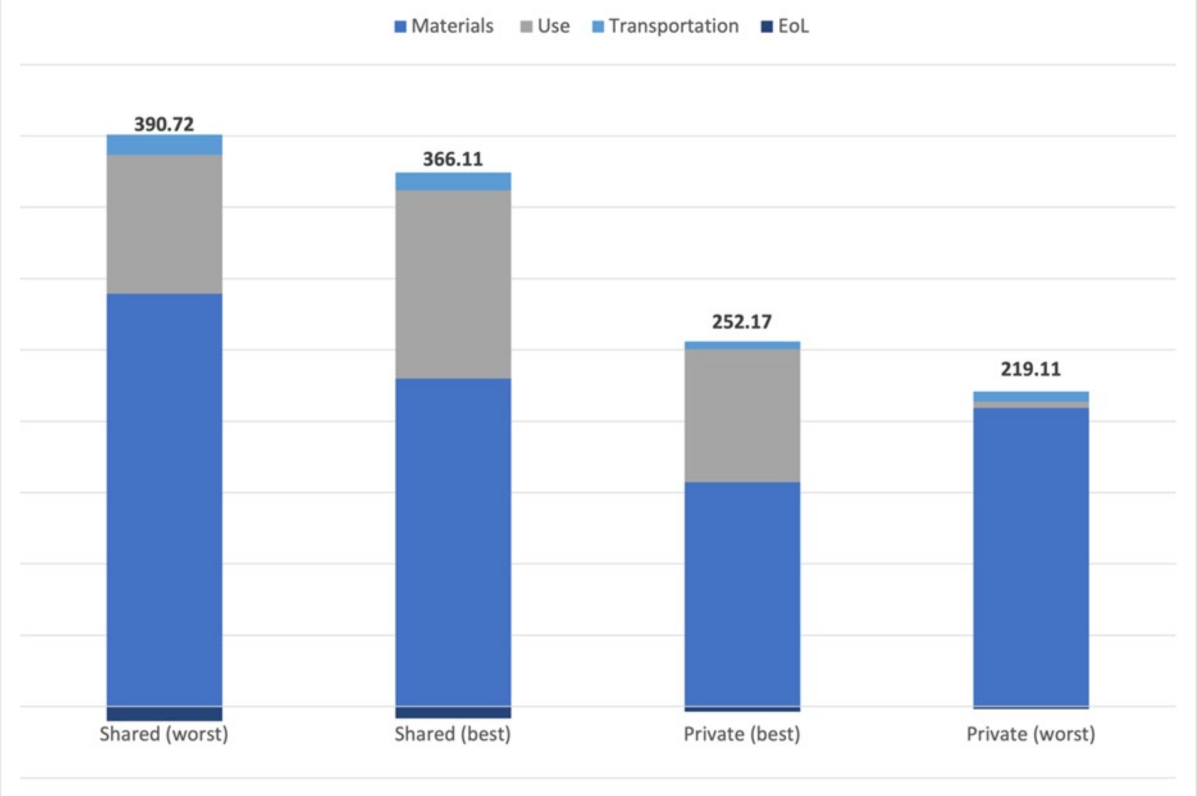

Figure 13: Comparison of total life cycle emissions for shared vs. private e-scooters under best and worst case scenarios

Table 32 and Figure 14 provide a comparison of emissions from shared and privately owned e-scooters under best and worst case scenarios. The assessment reveals that shared e-scooters in the best-case scenario (27 kg mass, 12,000 km lifespan) result in 366.11 kg CO2e in total emissions, indicating a more favourable environmental performance compared to the worst-case scenario (34 kg mass, 6,529 km lifespan) which totals at 390.72 kg CO2e. This disparity is primarily due to differences in materials and use-phase emissions. For shared e-scooters, this results in per passenger per km emissions of a worst case of 0.060 kg per km of CO2e and a best case of 0.031 kg per km of CO2e.

For private e-scooters, the best-case scenario (15 kg mass, 12,000 km lifespan) shows a total emission of 252.17 kg CO2e, while the worst-case scenario (20 kg mass, 1,100 km lifespan) has significantly lower emissions at 219.11 kg CO2e, predominantly due to the remarkably lower usage emissions, despite the reduced lifespan. **For private e-scooters, this results in per passenger per km emissions of a worst case of 0.199 kg per km of CO2e and a best case of 0.021 kg per km of CO2e.**

Table 32: Comparison of emissions from shared and privately owned e-scooters under best and worst case scenarios

Emissions /km	Best case	Worst case	Unit
Private e-scooters	0.021	0.199	kg per km of CO2e
Shared e-scooters	0.031	0.060	kg per km of CO2e

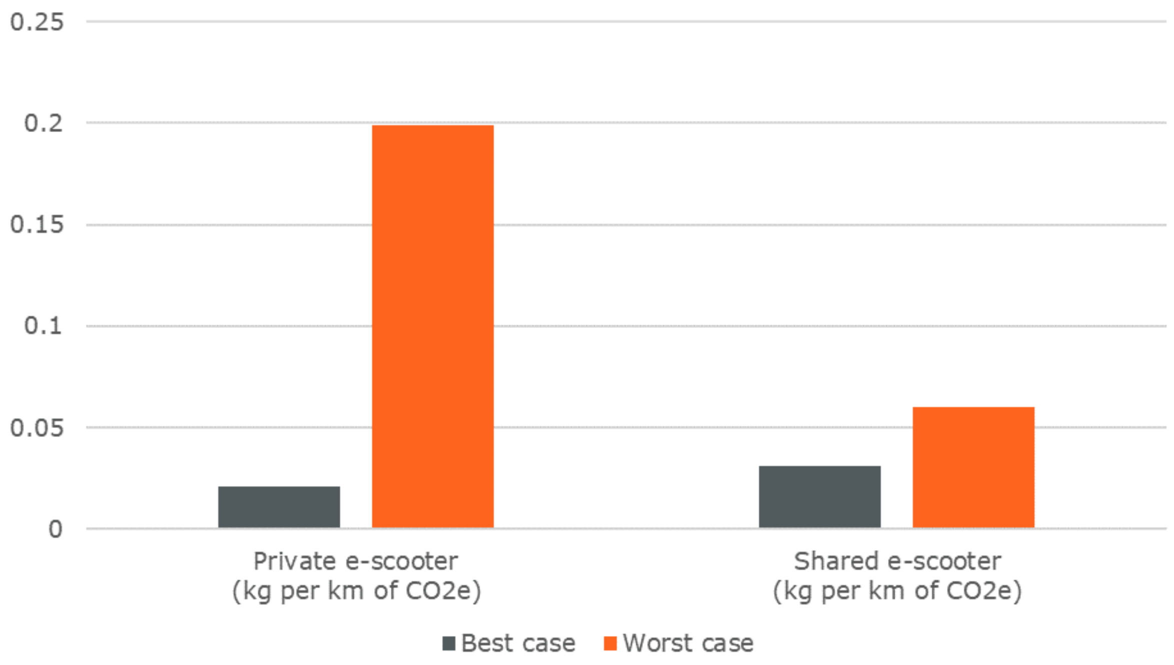

Figure 14: Comparison of per passenger per km emissions from shared vs. private e-scooters under best and worst case scenarios

10.3.2 Material contributions to life cycle emissions

The materials analysis for e-scooters (Figure 15) highlights aluminium as the predominant contributor to emissions, with figures ranging from 47.82 kg CO2e for the lightest private e-scooter to 112.79 kg CO2e for the heaviest shared e-scooter. Batteries follow, with emissions contributions of 40.54 kg CO2e to 54.12 kg CO2e, depending on the scooter's type and mass. Electric motors and electronics also represent significant emission sources, with electric motors contributing between 27.90 kg CO2e and 43.62 kg CO2e and electronics between 33.24 kg CO2e and 44.42 kg CO2e across the assessed models.

Comparatively smaller but still impactful, plastic parts account for emissions ranging from 3.40 kg CO2e to 17.72 kg CO2e. Steel and rubber, materials fundamental to the structure and operation of e-scooters, show lower emissions footprints, from 2.08 kg CO2e to 7.54 kg CO2e for steel and 2.24 kg CO2e to 9.21 CO2e kg for rubber. The analysis reveals a consistent trend: as the mass of the e-scooter decreases, so does the impact of each material on the overall emissions.

These figures indicate the significant role of material selection in the environmental performance of e-scooters. Reducing the mass of materials, particularly aluminium, and enhancing component efficiency could lead to lower total carbon emissions. Such improvements are integral to the development of sustainable transport solutions within urban environments.

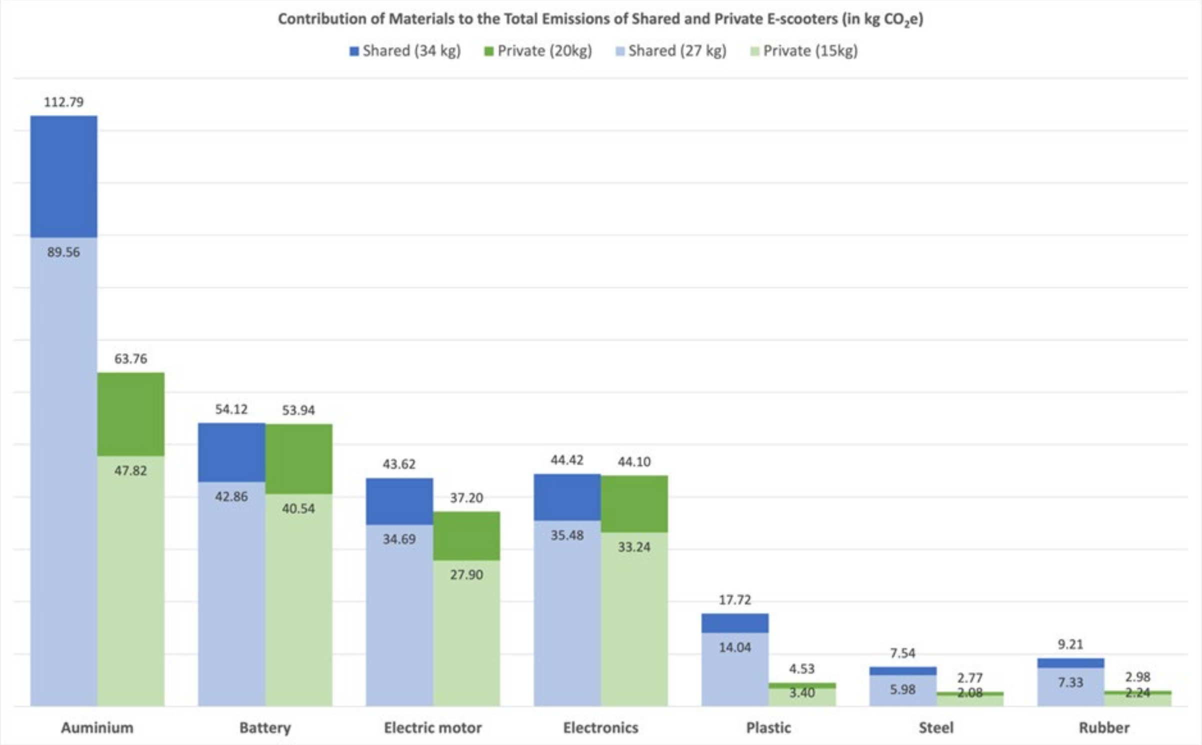

Figure 15: Contribution of materials to the total emissions of shared and private e-scooters

10.3.3 Breakdown of use stage emissions

Maintenance emissions are linked to the need for part replacements or repairs. In the best-case scenario, shared e-scooters generate 35.61 kg CO2e. However, the worst-case scenario sees an increase to 44.94 kg CO2e. This rise is attributed to the heavier assumed mass (34 kg) of shared e-scooters in the worst-case scenario, which could necessitate more robust or additional parts, thus leading to increased emissions. For private e-scooters, maintenance emissions are 45.65 kg CO2e in the best-case scenario. This higher emission figure in the best-case scenario includes the assumption of a full battery replacement. In contrast, for shared e-scooters, the best-case scenario assumes a mere 0.2 of a battery replacement, due to the fleet operation model.

Operational emissions are exclusive to shared e-scooters. They are reported at 48.52 kg CO2e in the best-case scenario, dropping to 26.40 kg CO2e in the worst-case scenario, reflecting the logistics of distribution and collection unique to shared scooters.

Charging emissions are at 47.67 kg CO2e for shared e-scooters in the best-case scenario and decrease to 25.94 kg CO2e in the worst-case scenario, showing the variance in energy consumption. Private e-scooters match this in the best-case scenario but reduce to 4.37 kg CO2e in the worst-case scenario.

In summary, (Table 33) the higher maintenance emissions for shared e-scooters suggest intensive use and a more frequent need for part replacements. In contrast, maintenance emissions for private e-scooters are primarily due to battery replacements (assumed in the best-case). Private e-scooters also tend to have longer operational lifespans, which leads to increased charging emissions. Efficient maintenance and charging practices are essential for minimising the environmental impact of e-scooters. Enhancing the durability of shared e-scooters and improving the efficiency of the power grid used for charging can significantly reduce emissions during the usage phase.

Table 33: Total emissions per vehicle

Emissions source	Shared (best)	Shared (worst)	Private (best)	Private (worst)
Maintenance (kg CO2e)	35.61	44.94	45.65	N/A
Operation (kg CO2e)	48.52	26.40	N/A	N/A
Charging (kg CO2e)	47.67	25.94	47.67	4.37
Total (kg CO2e)	131.80	97.28	93.32	65.07

10.3.4 Emission comparison of different transport modes

To establish a comparison with alternative modes, the GHG conversion factors (Scope 3) of motorised vehicles published by DESNZ and DEFRA (GOV.UK, 2023) are utilised. Corresponding figures for bikes and e-bikes are cited from Beryl's sustainability report (Beryl, 2023), as depicted in Figure 16.

The comparative analysis of emissions per passenger per km (in kg CO2e) between e-scooters and other transport modes provides a clear perspective on the environmental impact of various transportation options. Shared e-scooters in the worst-case scenario emit 0.060 kg CO2e per kilometre, which is significantly reduced to 0.031 kg CO2e per kilometre in the best-case scenario, highlighting the potential benefits of optimised shared transport systems. Private e-scooters emit even less in the best-case scenario at 0.021 kg CO2e per kilometre, but the worst-case scenario sees a substantial increase to 0.199 kg CO2e per kilometre, underlining the variability within private use depending on user behaviour and maintenance practices.

Traditional bikes, with an average emission of 0.027 kg CO2e per kilometre, continue to be a highly environmentally friendly option. This figure is a general average for bikes, reflecting their overall sustainability. In contrast, the best-case scenario for a private e-scooter, at 0.021 kg CO2e per kilometre, represents an extreme figure achieved under optimal conditions. As the energy grid shifts towards greater reliance on renewable sources, it is anticipated that the life cycle emissions of e-scooters, which depend on this energy for charging, will decrease. Consequently, this shift will also lead to a reduction in emissions per kilometre for e-scooters, enhancing their sustainability credentials in terms of distance travelled. E-bikes have a slightly higher emission value at 0.075 kg CO2e per kilometre, yet they remain a low-emission alternative compared to motorised vehicles. Motorcycles stand at 0.114 kg CO2e per kilometre, while local buses average at 0.102 kg CO2e per passenger per kilometre, which could be considered as a competitive option for sustainable urban travel, especially when considering their potential for electrification and their role in reducing traffic congestion through mass transit.

Cars show a wider range of emissions, with diesel cars at 0.170 kg CO2e per passenger per kilometre and petrol cars at 0.164 kg CO2e per passenger per kilometre, markedly higher than e-scooters and indicative of the heavier carbon footprint of single-occupancy vehicles. Battery Electric Vehicles (BEVs) represent the lowest emissions amongst motorised vehicles at 0.055 kg CO2e per passenger per kilometre, surpassing even the worst-case scenario for shared e-scooters, demonstrating the potential of electric vehicles in reducing transportation-related emissions.

It is evident that while e-scooters, particularly in shared systems, offer a lower-emission alternative to traditional motorised transportation. The data suggests that the adoption of e-scooters, especially if combined with a shift towards electric and non-motorised vehicles, could significantly contribute to the reduction of transportation emissions. However, the sustainability of e-scooters, especially in private use cases, relies heavily on user practices and system management. Therefore, it is crucial for policies and infrastructure to encourage not only the adoption of low-emission vehicles but also to support the sustainable operation and maintenance of these systems to maximise their environmental benefits.

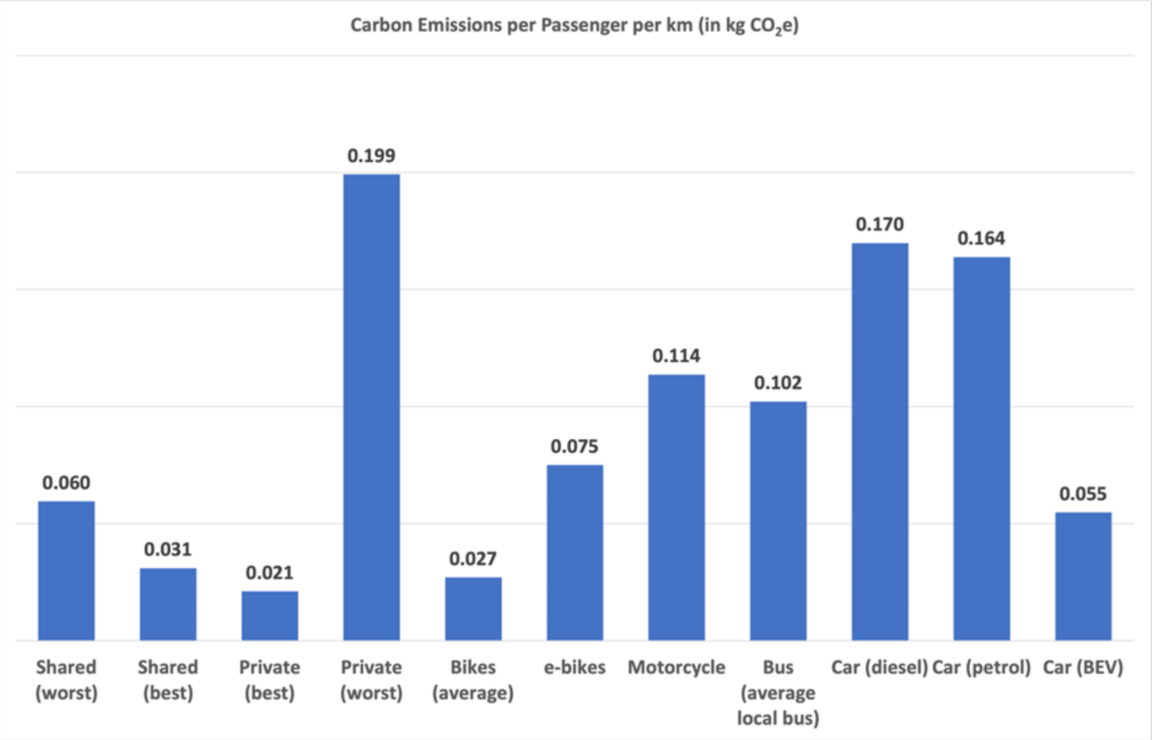

Figure 16: Carbon emissions per passenger per km for different modes of transport

10.4 Opportunities to reduce e-scooter emissions

10.4.1 Materials & manufacturing

Reduce mass of e-scooters: For shared e-scooters, reducing the mass from 34 kg to 27 kg translates to a 20.5% (59.48 kg CO2e) decrease in emissions from materials. For private e-scooters, a reduction from 20 kg to 15 kg results in a 24.9% (52.06 kg CO2e) reduction. This implies that for every 1 kg of material mass reduced, there could be an emission saving of between 8.50 kg CO2e and 10.41 kg CO2e, depending on the e-scooter type. Thus, the recommendation is to prioritise lightweight design in the manufacturing of both shared and private e-scooters, targeting the lowest feasible mass. This strategy not only aims to cut material emissions but could also improve operational efficiency, offering benefits such as an increased range per charge and lower maintenance needs, all contributing to the e-scooters' sustainability.

Carbon fibre, renowned for its strength and lightweight attributes, holds potential for significantly reducing the mass of e-scooters when used as a structural material. This reduction could enhance the operational efficiency and extend the range per charge of the e-scooters. However, the environmental cost of producing carbon fibre is substantial, with emissions for producing 1kg of carbon fibre standing at 24.83 kg CO2eq/kg for conventional methods and 19.29 kg CO2eq/kg for advanced methods -compared to 7.59 kg CO2eq/kg for aluminium – (Kawajiri, K. and Sakamoto, K., 2022). Additionally, its use as a structural material introduces complexities in recycling, especially when contrasted with more easily recyclable materials like aluminium. Consequently, this study acknowledges that while the use of carbon fibre for structural components in e-scooters could decrease mass and material emissions, a detailed assessment is imperative. This assessment must account for the amount of carbon fibre needed for optimal structural integrity, the emissions involved in its production, and the feasibility and advancements in its recycling technology.

Recycled aluminium: Shared e-scooters, incorporating between 11.80 to 14.86 kg of aluminium, and private e-scooters, with 6.30 to 8.40 kg, currently generate substantial emissions when assuming to use virgin aluminium — 89.56 to 112.79 kg CO2e and 47.82 to 63.76 kg CO2e, respectively. Transitioning to recycled aluminium, with an emission factor of only 0.038 kg CO2e per kg, reduces these figures dramatically to just 0.45 to 0.56 kg CO2e for shared e-scooters, and 0.23 to 0.31 kg CO2e for private e-scooters. This enables potential savings of 89.11 to 112.22 kg CO2e for shared e-scooters and 47.58 to 63.44 kg CO2e for private e-scooters, respectively. Incorporating recycled aluminium into e-scooter manufacturing is feasible due to its availability in the supply chain, but it carries a higher cost compared to virgin aluminium. This cost increase is attributed to the processes involved in collecting, sorting, and reprocessing the material.

Recycled plastic and use bio-materials: Plastics are used in shared (2.48-3.13 kg) and private e-scooters (0.60-0.80 kg), with associated carbon emissions of 14.04-17.72 kg CO2e and 3.40-4.53 kg CO2e, respectively, when using virgin plastics. Utilising proxy data from ecoinvent, emissions from 1 kg of recycled plastics range from 0.51 to 0.76 kg CO2e, depending on the recycling technologies and locations. This leads to potential emission savings of 12.78-15.34 kg CO2e (86.57%-91.03%)

for shared e-scooters and 3.09 to 3.92 kg CO2e (86.53 %-90.88 %) for private e-scooters by using recycled plastics. Bio-derived plastics have an emission range of 1.39 to 5.19 CO2e per kg, varying based on the ingredients and technologies used. This results in potential emission savings of 1.48-10.59 kg CO2e (8.35%-75.43%) for shared e-scooters and 0.38 to 2.57 kg CO2e (8.39%-75.59%) for private e-scooters by opting for bio-derived plastics. Switching to recycled plastics and bio-plastics for e-scooter production may be more economically feasible than recycled aluminium, typically due to their lower cost.

Adopt battery recycled content targets: Set progressive targets for recycled content in batteries, starting with a feasible percentage and increasing as technology and processes improve. By incorporating recycled battery content, the emissions from battery production can be reduced considerably. Assuming a 50 % adoption rate of recycled materials could translate into reducing the battery-related CO2e emissions by half, making a significant impact on the overall carbon footprint of e-scooter production. While recycled batteries are beneficial for emission savings, the cost might be higher due to the current limited supply and the intricate process of battery recycling. However, as the technology advances and more recycled material becomes available, these costs are expected to decrease, leading to economies of scale.

UK manufacturing / greener energy mix country manufacturing: The total electricity consumption for manufacturing an e-scooter is estimated to be between 16.82 and 19.22 kWh. These estimates are based on data from the ecoinvent database, accounting for three key processes: scooter frame production (0.15-0.17 kWh), scooter powertrain production (5.43-6.21 kWh), and scooter battery production (11.24-12.84 kWh). This data, sourced from first-generation e-scooter production, has been adjusted according to mass ratios. In 2022, the emission factor for the Chinese national grid was 0.581 kg CO2e/kWh (MEE, 2022), the most recent figure at the time of this report's writing. The average emission factor for the UK national grid in 2023 is 0.207 kg CO2e/kWh. The shift in greener electricity mix results in an approximate emission saving of 6.29-7.19 kg CO2e per e-scooter, equating to a 64.37 % reduction.

10.4.2 Transportation

On-shore production and utilise electric vans for distribution: The emissions from shipping e-scooters from China to the UK via sea container are estimated to be between 5.86-7.38 kg CO2e for shared e-scooters and 3.25-4.34 kg CO2e for private e-scooters, accounting for approximately 60 % of the emissions in the Transportation stage. If production were to occur in the UK, this portion of emissions could be entirely avoided.

Currently, all UK local distribution for e-scooters is assumed to carry out using fossil fuelled vehicles in the modelling, contributing approximately 2.52-3.18 kg CO2e for shared and 1.4-1.87 kg CO2e for private e-scooters. These account approximately 21 % of the total Transportation emissions. If electric vans (emitting 0.00024243 kg CO2e per km) (GOV.UK, 2023) were used, the emissions for UK land transportation would drop to 0.13 kg CO2e, potentially saving approximately 2.4 kg CO2e, which is a 95 % reduction in emissions.

10.4.3 Use

Use more renewables to charge – greener energy mix: The charging requirements for shared e-scooters range from 125-230 kWh of electricity throughout their lifespan, varying based on worst or best-case scenarios. These rates establish the baseline for charging emissions at 25.94-47.67 kg CO2e for shared e-scooters, using an emission factor of 0.207 kg CO2e/kWh. Transitioning to renewable energy sources for charging could lead to significant emission reductions for shared e-scooters. By utilising solar panels, with an emission factor between 0.08-0.126 kg CO2e per kWh, or wind energy, at 0.01-0.02 kg CO2e per kWh, the potential emission savings could range from 10.61-29.25 kg CO2e for solar and 23.43-45.37 kg CO2e for wind energy.

Enhancing Tyre Durability in E-Scooters: Developing more durable tyres capable of lasting the entire 12,000 km lifespan in the best-case scenario for shared e-scooters could lead to an approximate emission saving of 8 kg CO2e per e-scooter. This improvement directly addresses the current requirement of replacing tyres twice within this distance, which contributes approximately 40 % to the Maintenance emissions. Further analysis is required to understand impact of more durable tyres on puncture resistance and grip.

Optimising Battery Performance in Private E-Scooters: To augment the overall sustainability of private e-scooters, a key focus should be on enhancing battery performance, particularly to extend its lifespan. Currently, achieving a 12,000 km lifespan in private e-scooters requires at least one battery replacement. By improving the battery system design and charge-discharge management to last the entire 12,000 km without the need for replacement, an approximate 20.27-26.97 kg CO2e emission saving per private e-scooter can be achieved. Considering the substantial contribution of the battery to life cycle emissions, extending battery life can markedly reduce the environmental impact associated with battery production and disposal. EU proposed battery regulations to improve longevity of smartphones and tablets set requirements to maintain 83% capacity after 500 charge-discharge cycles, and 80% after 1000 cycles. This is in line with automotive batteries battery electric vehicles (500 full charge-discharge cycles of an EV with typical 300 km range would have a life of 150,000 km). An e-scooter with range of 20 – 30 km would achieve 10,000 – 15,000 km over 500 charge-discharge cycles.

Extending Life: Extending the life of e-scooters, particularly privately owned vehicles, is critical to reducing emissions per kilometre. There have been strides in this for shared e-scooters with improvements needed for:

- Durability: Increase the durability of non-consumable e-scooters components to ensure they can achieve at least 12,000 km of operational life. Use high-quality, robust design and materials engineered for extended life.
- Serviceability: Routine service procedures should be introduced to ensure e-scooters are well maintained for longevity. Instructions and guidance for servicing/maintenance should be provided by manufacturers.
- Repairability: In order to prevent lightly damaged or worn products being discarded, e-scooters should be designed and manufactured to be easily repairable, with a focus on modularity for simple disassembly using conventional, available tools.

- Availability of Spare Parts: Secure a reliable supply of spare consumable or frequently damaged parts for both shared and private e-scooters, aiming to support their extended lifespan goals. This can be common parts shared across a variety of brands (such as tyres, bulbs and bearings), or replacement parts specific to an e-scooter design (structures, fairings and guards). This is already offered by some manufacturers. The manufacturer/retailer should ensure availability of spare parts for at least 7 years. This is in line with products including televisions, but less than the 10 years for some spare parts for other appliances like washing machines, under right to repair regulations.

Measures to extend life to consider are:

- Requirements should be put in place on manufacturers of e-scooters sold or provided as a service in the UK to provide all information necessary to diagnose, service, maintain, or repair the vehicle; offer for sale any required tools or equipment; and provide the information that enables third parties to manufacture tools or equipment with the same functional characteristics.
- Consideration should be made to create similar “right to repair” regulations for e-scooters that exist for other products in the EU’s Ecodesign for Energy-Related Products and Energy Information Regulations 2021. Recent additions to the list of products categories include battery powered devices including mobile phones and tablets, with mandating swappable batteries proposed.
- Concerns over the safety of replacement or repaired batteries should be prioritised over sustainability. It is stated, in the pre-amble of Regulation 2023/1542, paragraph (40), that: “*For repaired LMT batteries, the Commission will prepare rules on the safety of micromobility devices, building on experience at national and local levels of safety requirements, as announced in the communication of the Commission of 14 December 2021 on ‘The new EU Urban Mobility Framework’.”* However, there is no timeline provided for this activity.

Warranty: For private e-scooters, extending the warranty period included with the purchase of the product to at least two years, up from the typical 6-12 months, is advisable. Measures to consider are:

- An extended warranty would encourage manufacturers to build more durable and repairable e-scooters. Less durable or repairable (and therefore less sustainable) vehicles will not be viable to sell with an extended warranty due to the costs incurred from frequently replacing or repairing vehicles.
- Special considerations may be needed for the warranty rights on specific components, for example the battery could also be limited to a maximum number of charge cycles or consider an expected loss of useable battery capacity/range. However, electronic components often excluded from e-scooter extended warranties including controllers, screens, motors and batteries should be included in scope of the warranty.
- Consumable items such as tyres and brake pads may be excluded from the warranty as there is an expectation they will wear and require replacement over the life of the product. Spare parts should be made available as previously described.

- It should be possible for a warranty to be transferred to a new owner, maintaining the warranty period from the date of original purchase.
- Warranty durations for e-scooters in certain European countries are already two years. Currently manufacturers provide 12-month warranties in the UK and two-year warranties in France for the same product (cf Pure Electric warranty information – UK and France).

These measures may have an impact on the initial cost of the product to the consumer and by extension the manufacturer, due to increased design, manufacturing and product support costs. However, it is envisaged that the implementation of these measures will lead to a higher quality product for consumers, with an improved lifespan and reduced environmental impact.

10.5 End of life

Improve vehicle recycling rates: The vehicle recycle rate currently sits at 90 % for shared e-scooters, 31.1 % for the worst-case, and 90% for the best-case scenarios of private e-scooters. This results in the EoL emission savings for shared e-scooters ranging from 8.16-10.3 kg of CO2e, and 1.7-4.92 kg of CO2e for private e-scooters, varying based on the worst or best cases. If the vehicle recycle rate can be maintained at 90 % for the worst-case scenario of private e-scooters, this could save 2.45-3.22 kg of CO2e. Additionally, if the vehicle recycle rate for shared e-scooters reaches 98%, this could result in a saving of 0.75-0.93 kg of CO2e.

Improve material recycling rates: In this study, by comparing the material recycle rate adopted for the UK, it has been demonstrated to have superior performance compared to those in other regions. The primary critical issue is the recycling performance of EoL batteries, which is a worldwide challenge. The assumed recycle rate for these batteries is currently 65 % for this study. The emission savings associated with this rate are estimated to be between 0.56-2.16 kg of CO2e for both shared and private e-scooters, accounting for approximately 43 % of the emission savings in the EoL stage. If the recycle rate of EoL batteries could reach 85%, the emission savings could potentially increase to between 0.18-0.66 kg of CO2e per e-scooter.

10.5.1 Overall

Extending the lifespan of e-scooters, both shared and private, emerges as a pivotal factor in reducing their total life cycle emissions. The longevity of an e-scooter directly influences its environmental impact, with a longer lifespan leading to a substantial decrease in emissions per kilometre.

For both private and shared e-scooters, our overall recommendation is therefore to extend the mandatory warranty period to at least 2 years, with consideration given to a longer warranty period.

For shared e-scooters, the intense usage and frequent circulation often lead to quicker wear and tear. By focusing on enhancing their durability, the frequency of replacing parts, or the entire scooter, can be reduced. This extension in usable life not only diminishes the need for manufacturing new scooters — a process with considerable emissions — but also lowers the emissions attributed to the use phase per kilometre, as the emissions are spread over an extended period.

Similarly, for private e-scooters, extending lifespan plays a critical role. Private e-scooters, typically subjected to less rigorous use than shared ones, have the potential for an even longer lifespan. By ensuring their longevity, the total emissions produced during manufacturing and disposal phases are amortised over a greater number of kilometres travelled, resulting in a lower emission rate per kilometre.

Beyond the recommendation for an extended mandatory warranty, below (Table 34) we outline further additional opportunities (beyond the scope of technical regulations) to reduce the life cycle emissions of e-scooters:

Table 34: Potential emission savings

Opportunity	Potential emission savings
Reduce mass of e-scooters	Every 1 kg of material mass reduced, there could be an emission saving of between 8.50 kg CO2e and 10.41 kg CO2e.
Recycled aluminium	Potential savings of 89.11 to 112.22 kg CO2e for shared e-scooters and 47.58 to 63.44 kg CO2e for private e-scooters.
Recycled plastics	Potential emission savings of 12.78-15.34 kg CO2e (86.57%-91.03 %) for shared e-scooters and 3.09 to 3.92 kg CO2e (86.53 %-90.88 %) for private e-scooters.
Bioplastics	Potential emission savings of 1.48-10.59 kg CO2e (8.35 %-75.43 %) for shared e-scooters and 0.38 to 2.57 kg CO2e (8.39 %-75.59 %) for private e-scooters.
Adopt battery recycled content targets	A 50 % adoption rate of recycled materials could translate into reducing the battery-related CO2 e emissions by half.
UK manufacturing	The shift in greener electricity mix results in an approximate emission saving of 6.29-7.19 kg CO2e per e-scooter, equating to a 64.37 % reduction.
On-shore production and utilise electric vans for distribution	If production were to occur in the UK, the emissions of international sea containership could be entirely avoided. If electric vans were used, the emissions for UK land transportation would drop to 0.13 kg CO2e, potentially saving approximately 2.4 kg CO2e.
Use more renewables to charge – greener energy mix	The potential emission savings could range from 10.61-29.25 kg CO2e for solar and 23.43-45.37 kg CO2e for wind energy.
Enhancing Tyre Durability in E-Scooters	Approximate saving of 8 kg CO2e per e-scooter by avoiding the need to replace tyres twice within a 12,000 km lifespan.
Optimising Battery Performance in Private E-Scooters	An approximate 20.27-26.97 kg CO2e saving per e-scooter by designing batteries to last the entire 12,000 km without replacement (500 full charge-discharge cycles).
Extend life	Improve durability, serviceability, repairability and availability of spare parts do increase total distanced travelled by e-scooters over their life could have up to a tenfold reduction in kg CO2e per km.
Improve vehicle recycling rates	If the vehicle recycle rate can be maintained at 90 % for the worst-case scenario of private e-scooters, this could save 2.45-3.22 kg of CO2e. Additionally, if the vehicle recycle rate for shared e-scooters reaches 98%, this could result in a saving of 0.75-0.93 kg of CO2e.
Improve material recycling rates	If the recycle rate of EoL batteries could reach 85 %, the emission savings could potentially increase to between 0.18-0.66 kg of CO2e per e-scooter.

11 Discussion

This report, and the project on which it was based, focused on some specific areas of the technical characteristics of e-scooters. In this chapter we will attempt to bring together those disparate areas of technical regulation and provide an overview of the philosophy that may be required in order to create a functional scheme of technical regulations that maintains and promotes safety, accessibility and sustainability while at the same time encouraging the development of new designs of machine to fill niches in the transport ecosystem.

Given the existing prevalence of privately owned e-scooters in use in public places, despite that being illegal, there is a very real risk that any new scheme of regulation would simply be ignored. It is therefore important to balance perfectionism and pragmatism in the way these regulations are drafted and enforced. There are clear opportunities to improve the personal mobility of a wide range of people, while reducing dependence on cars and other less sustainable transport modes. Those opportunities could easily be missed if excessively rigid restrictions were placed on the design and use of e-scooters. However, it is also important to remember that any new transport mode will inevitably bring with it a new set of risks and has the potential to reduce access to public spaces for those who may be impacted by a new vehicle type in the environment. Some of those risks, such as incidents caused by structural failures, can be mitigated through good technical regulations or standards, but others require a more holistic approach which takes into account user behaviours, knowledge and training, the nature and availability of infrastructure and the broader transport regulatory framework into which e-scooters might be incorporated, including speed limits for other vehicles, driver training and requirements set out in the Highway Code.

One key consideration in the development of this future scheme of regulations is the experience, competence and organisational cultures of the organisations that will design, produce and maintain these novel transport devices. Many are new entrants to the transport industry having either pivoted from the production of consumer electronic goods or started as new companies. This inexperience sometimes manifests itself through poorly designed products with short life expectancy and little or no after sales support. The marketing of e-scooters through electronics shops and online retailers, rather than an experienced dealership network can also leave users without an adequate advice and support network when purchasing and using their e-scooters. This deficiency places a significant burden on regulation to ensure that public safety is maintained and that good quality, sustainable and accessible products become the norm in the e-scooter industry. However, these concerns must be balanced carefully against the desire to promote innovation. The need then is for regulatory “guard rails” which ensure that e-scooters have a minimum level of safety, accessibility and sustainability without being so prescriptive and restrictive that they stifle the development of the industry, as we have seen with the failure of the L1e-A sub-category in the EU, which has failed to attract any manufacturers to develop products suitable for the sub-category.

Currently “machines” including EAPCs, e-scooters and indeed circular saws and industrial food mixers are regulated under the Supply of Machinery (Safety) Regulations 2008. While the regulation is mandatory, the means by which compliance with it may be demonstrated is more flexible, using a scheme of largely voluntary standards which manufacturers, importers and distributors are expected, but not required, to comply with specifically, provided that the fundamental requirements of the regulation are met via some appropriate means. Meanwhile “vehicles” including mopeds, motorcycles, cars etc. are subject to mandatory type-approval regulations. These vehicle regulations specify in detail a range of tests to be performed by a designated technical service before an approval may be issued and also defines what constitutes a “type” and thus the level of divergence in design that is allowed before another approval is required. For vehicles, the approval process is administered by the Vehicle Certification Agency, a government body, who act as the gatekeepers to type-approval and thus ensure that any new design is safe and minimally harmful to the environment, within the limitations of regulations. Broadly then, we might consider the regulations applied to machinery as relatively “lighter-touch” and minimally disruptive to the development lifecycle of new products, while the type-approval process is more arduous and, primarily due to the requirement for approval by a government agency, a significant barrier to the development of new products. Thus, the product lifecycle of vehicle designs tends to be much longer than that of products that don’t require external approval.

One important lesson that can be drawn from vehicle regulations is their tendency to specify performance criteria rather than requiring specific designs, for example a braking distance rather than a brake disc diameter. This approach encourages innovation and the development of alternative solutions. This approach has been adopted by the German authorities in their eKFV regulation for e-scooters and other PLEVs, which defines amongst other requirements a series of obstacles that e-scooters must drive over in a satisfactory manner and a minimum deceleration rate that the braking system must be able to produce. This use of readily accessible performance tests makes it much easier for enforcement authorities to determine whether or not a machine is compliant with regulation without the need for complex and time-consuming engineering assessment. This approach is however heavily dependent on the competency of the manufacturer to produce designs that are durable and sustainably produced. This regulatory approach can be augmented via voluntary standards, which can help to support manufacturers in the more complex areas of machine development, although as previously mentioned, the most relevant standard in this area currently is BS EN 17128:2020, which currently leaves a lot to be desired in its approach to structural integrity, durability and battery safety. In principle though the approach of having a light touch technical regulation that specifies a small number of key safety-related performance criteria augmented by a much more detailed voluntary standard would seem the optimum route to support the development of the e-scooter industry while maintaining safety, accessibility and sustainability.

An alternative approach would be to regulate the organisations that manufacture, import or distribute e-scooters. These organisations could be required to demonstrate certain competencies perhaps through the qualifications of their staff, membership of professional bodies or certification under appropriate quality control systems e.g. ISO9001. This approach would however be a deviation from the current norm in which it is the performance of the product rather than the organisation responsible for it that is the primary subject of assessment. This approach could also represent a significant barrier for new entrants to the market and may therefore reduce the potential for innovation in the industry.

12 Conclusions and recommendations

12.1 Vehicle stability by design

We conducted a review of existing international standards applied to the stability and controllability of e-scooters and EAPCs (Section 7). We found that the practical tests developed by the German authorities are increasingly being adopted as the benchmark for e-scooter stability in the EU. For example, Spain have incorporated these tests into their 2022 Manual of Characteristics of Personal Mobility Vehicles. This series of tests is designed to replicate the types of obstacle that an e-scooter is likely to encounter when ridden on city streets. The tests are easy to replicate requiring no special test equipment other than the obstacles themselves, which can be easily fabricated. These tests are, to a significant extent, subjective, and rely on the skill and judgement of the test rider. However, we found no truly objective test of two wheeled e-scooter stability and indeed the nature of such machines means that their stability is heavily influenced by the dynamics of the rider.

We recommend that the stability tests specified in the German eKFV standard and Spanish *Manual of Characteristics of Personal Mobility Vehicles* be adopted as the baseline for stability testing of e-scooters (see Section 7.2).

We considered the possibility that specifying certain design parameters e.g. wheel diameter, wheelbase or footplate dimensions might be beneficial in ensuring the stability (and therefore safety) of e-scooters. There is good evidence that, for example, larger wheels provide better ride quality and are less susceptible to the effects of potholes and kerbs. However, we found no precedent for mandating design decisions of this nature in other vehicles, e.g. EAPCs or L-category vehicles. We also found no definitive evidence that could be used to select a specific wheel diameter that would be significantly safer than a smaller one if factors such as tyre design, suspension and steering geometry were neglected. Thus, we do not recommend the mandating of a specific minimum wheel diameter.

12.2 Structural integrity

We conducted a range of activities (Section 6) including a review of the structural integrity requirements specified in BS EN 17128:2020 and BS EN 15194:2017, reviewed failure reports collected as part of the ongoing trial of shared e-scooter, conducted interviews with industry stakeholders and applied our own engineering judgement to formulate the following recommendations on structural integrity. We found that the requirements for structural overload and fatigue in BS EN 17128:2020 do not adequately reflect the likely operating scenarios to which e-scooters will be subjected in use. This deficiency could lead to premature structural failures, potentially leading to collisions and consequent injury, and prematurely curtailing the useful life of the machine, causing additional environmental damage.

We therefore recommend that DfT works with the British Standards Institute (BSI) to lobby for the revision of BS EN 17128:2020 to incorporate more robust requirements for both structural overload and fatigue. These requirements should be based on reasonably foreseeable worst case load cases, e.g. use by a 95th percentile male rider riding 10,000 km. The standard should as far as is reasonably practicable seek to eliminate the possibility of the most dangerous structural failures, i.e. those affecting the steering structure, since they almost unavoidably lead to dangerous collision kinematics in which the rider is thrown forwards towards the pavement and broken structure. As a minimum we recommend that overload tests be required for the handlebars, stem, steering tube, front fork and the mounting point of the steering system to the frame. We also recommend that the complete machine be subject to fatigue testing, at maximum design mass, in a manner that replicates reasonably foreseeable worst case loadings for the handlebars, stem, steering tube, front fork and frame attachment point.

A revision to BS EN 17128:2020 is likely to require a lengthy process of negotiation across Europe, during which manufacturers will be devoid of appropriate guidance. We recommend in the meantime therefore that DfT, or another appropriate government body, initiates the creation and promulgation, by the industry, of a set of best practice guidelines for the engineering of e-scooter structures.

12.3 Vehicle configuration and integration with vehicles for disabled people

Most countries forbid the fitting of seats to e-scooters, and some, including the UK in the current DfT led trial of shared e-scooters, restrict e-scooters to having only two wheels which are aligned along the longitudinal axis of the machine. We considered the implications of allowing e-scooters to be fitted with seats and to be fitted with more than two wheels. These innovations have the potential to create two regulatory conflicts, the first with the L-category regulations under the assimilated EU Regulation No 168/2013 and the second with The Use of Invalid Carriages on Highways Regulations 1988. We undertook a range of activities including reviewing the existing L-category regulations, workshops with disability charities (Section 4.3and 4.5), interviews with individual disabled people (Section 4.4) and a review of existing regulations (Section 5). The following recommendations are based on those activities.

The Use of Invalid Carriages on Highways Regulations 1988 contain requirements for both the technical characteristics of the vehicle, and stipulation regarding the manner of its use. Some of the disability charities we spoke to expressed dissatisfaction with the current products made available under the existing invalid carriage regulations, and further expressed the desire that these regulations be repealed and replaced by a set of micromobility regulations that would allow for the creation and use of vehicle types that supported the mobility needs of all people, whether they were regarded as being disabled or not. A similar finding emerged from the interviews with disabled people, with one of the overarching themes being the desire for flexibility in the design of e-scooters to fit the needs of different users.

12.3.1 Seated e-scooters

Regulation (EU) No 168/2013 excludes from its scope vehicles without seats and vehicles whose seats have an R point lower than 540 mm for L1e, L3e and L4e and 400 mm for L2e, L5e, L6e and L7e. This exclusion has been used in many jurisdictions to create the regulatory space into which standing e-scooters have been allowed. Most e-scooters with seats however fall within the definition of Regulation (EU) No 168/2013 and are thus treated as L1e-B mopeds for the purposes of both type-approval and user requirements. Since the UK has now left the European Union and is no longer obliged to comply with EU law in Great Britain (although EU law still applies in Northern Ireland), the DfT could choose to amend the assimilated EU Regulation 168/2013 in order to permit e-scooters with seats to be approved and used with a different set of technical and user regulations to mopeds. This would however require a new point or points of differentiation to be created between e-scooters with seats and L1e-B mopeds. The most obvious option would be to use maximum speed as that point of differentiation such that e-scooters would be classified as machines with a maximum speed of, for example, 15.5 mph, and L1e-B mopeds would be categorised as vehicles with a maximum speed of between 15.5 mph and 28 mph (the current limit for the category). In order for machines with seats and three or four wheels, the same change would need to be made to the definitions of L2e and L6e, although in practice this may be achieved by simply amending the overall scope of assimilated EU Regulation No 168/2013 to have a minimum speed of, for example, 15.5 mph. One possible consequence of this change is that machines that had previously been type-approved as L1e-B mopeds might become eligible for inclusion in this new scheme. Although in practice this is likely to be a handful of types at most, since the market for low-speed mopeds in the UK is limited, and becoming increasingly so in the EU, as national regulations on their use become tighter.

The DfT would also have to take a decision about the licensing regime and user requirements for seated e-scooters, although this would likely be part of the broader consideration of licensing requirements for e-scooters that will be required anyway. Many EU member states have alternative user requirements for mopeds with a top speed of 25 km/h compared to those with a top speed of 45 km/h, although in recent years requirements for the former have tightened considerably to bring them into closer alignment with the latter. Differences that persist include alternate age limits, permission to use cycle paths and requirements for registration, although only France permits riders of “light cyclomobiles” (the new light, low-speed moped category) to ride without a helmet. All EU member states now require riders of mopeds to hold a license or “pass-certificate” of some kind, although in some cases this can be obtained by passing a theory test alone.

The regulatory conflict between e-scooters with seats and The Use of Invalid Carriages on Highways Regulations 1988 is rather less acute than that with Regulation (EU) No 168/2013 since the former is primarily differentiated by the user group for which the machine is intended rather than its technical characteristics. In that respect at least a regulation permitting e-scooters with seats could co-exist with the existing Invalid Carriage regulations without the need for the latter to be amended. However, it is important to reiterate that there may be additional benefits to be derived by designing the new e-scooter regulations in such a way that they would provide the greatest accessibility to the widest range of potential users, which must therefore include permission to be fitted with a seat in addition to allowing machines that can be ridden while standing.

12.3.2 E-scooters with more than two wheels

Unlike allowing e-scooters to have seats, allowing e-scooters with more than two wheels does not create an acute regulatory conflict with existing regulations. While Regulation (EU) No 168/2013 categorises vehicles according to the number of wheels they have, the number of wheels is not a key criterion for inclusion in the scope of the regulation. There are already a number of three and four wheeled e-scooters on the market, one of which was tested in the course of this project. Allowing e-scooters to have more than two wheels would create regulatory space for greater innovation which could, for example, create new types that were more stable at low speeds than two-wheeled machines. In combination with permitting seated e-scooters, allowing machines with more than two wheels has the potential to facilitate the creation of new designs which serve a more diverse user group than standing two-wheeled machines.

Therefore, in order to make e-scooters as accessible as possible to the greatest range of users, and to facilitate innovation which may create new types with additional societal benefits, we recommend that e-scooters be allowed to be fitted with seats, in addition to allowing standing machines, and that e-scooters with 2, 3, 4 or more wheels be allowed.

12.4 Maximum mass

E-scooters are relatively lightweight machines which are often a fraction of the mass of their rider. The total laden mass of the machine has a critical effect on its ability to brake, steer and accelerate effectively, the structural integrity of the machine, and effects the severity of any collision that may occur. For these reasons we recommend that for the purposes of technical regulations it is more appropriate to regulate the maximum laden mass of the machine, since, for most applications, the mass of the rider will be significantly greater than the unladen mass of the machine itself. From a safety perspective, the total mass of machine, rider and any luggage they may carry is a more important metric than the mass of the machine in isolation, since by definition the machine can never be used in its unladen state.

We recommend that manufacturers should be required to declare both the unladen mass in running order and maximum laden masses of their machines. Requiring manufacturers to declare the maximum mass to which their machine has been designed will help to ensure that they design and test their machines in a way that fully considers the effect of maximum machine mass on vehicle systems such as brakes and that designs are effective under the worst-case loading conditions. Additionally, requiring manufacturers to declare the unladen mass of their machines will help users to make informed decisions about the suitability of a particular machine for their needs.

The choice of maximum mass requirement has implications for the desire to make e-scooters accessible to disabled people. Currently, a class 2 ‘invalid carriage’ is permitted to have a maximum unladen mass of 113.4 kg while a class 3 ‘invalid carriage’ is permitted to have a maximum unladen mass of 150 kg. Both class 2 and 3 machines are permitted a maximum unladen mass of 200 kg when fitted with necessary user equipment. These requirements are rather at odds with those applied internationally to e-scooters, for example Ireland now requires a maximum unladen mass of 25 kg, which has been chosen to place e-scooters outside of the scope of European Directive 2021-2118 on motor vehicle insurance, while Spain applies a 50 kg limit and Germany 55 kg.

The average unladen mass of the class 2 mobility scooters in our market survey (Table 7) was 43 kg (max 94 kg), with class 3 mobility scooters having an average unladen mass of 118 kg (max 165 kg), while the average maximum rider mass was 125 kg (max 160 kg) and 152 kg (max 180 kg) respectively and the average laden mass 164 kg (max 254 kg) and 279 kg (max 329 kg). Current mobility scooters are thus rather heavier than typical e-scooters and are also typically designed to accept a much heavier rider. This extra vehicle mass is in part due to the use of cheaper but much heavier lead acid batteries rather than the much lighter lithium based alternatives favoured by e-scooter manufacturers, however when defining a mass limit for e-scooters the various use cases should be considered in order to maximise the utility of e-scooters for as many people as possible whilst also minimising safety risks.

12.5 Maximum speed

Addressing the issue of speed restriction was not specifically within the scope of this project. However, there is a significant interaction between maximum speed and other areas of the investigation that were in scope, in particular the accessibility of e-scooters for disabled people. The selection of a ‘speed limit’ for e-scooters is intrinsically linked to user regulations, which are also outside the scope of this study. Factors such as mandatory rider training, where e-scooters are allowed to be ridden, the mandating of helmets and other protective equipment and the restrictions that may be placed on who can ride an e-scooter e.g. due to their age or health, all have an influence on the choice of a specific speed limit.

We recommend that technical regulations for e-scooters require them to have a system to limit their maximum speed, which is integral to the machine and cannot easily be manipulated by the user.

We heard from some disability charities that having the facility to ride on the footway is an important factor affecting the accessibility of e-scooters. This facility may also be considered beneficial for new riders who would otherwise be required to take their first rides on the open road, and less confident riders who do not feel safe mixing with traffic.

However, there is clear public concern that the riding of e-scooters on the footway is a threat to the safety of pedestrians, in particular those who have visual or hearing impairments or mobility difficulties.

There is a precedent in both The Use of Invalid Carriages on Highways Regulations 1988 and BS EN 17128:2020 for the provision of a rider operated control that can be used to limit the speed of a machine when it is used on the footway to 4 mph (6 km/h). We therefore recommend that, when preparing regulations for the use of e-scooters, DfT gives consideration to allowing the use of e-scooters on the footway in order to maximise their accessibility to disabled users and those who would feel unsafe riding on the road, but that such an allowance would be contingent to the mandatory provision of a speed limitation switch to limit the speed of the machine to 4 mph when used in such circumstances.

When considering a mandatory technical requirement for speed restriction it is also important to consider the ease with which such a measure could be defeated. Given the very simple architecture of most e-scooters it is not difficult for somebody with relatively limited technical skills to increase its top speed. It would therefore be very difficult for manufacturers to design e-scooters in such a way that their maximum speed could never be increased in service. Designing e-scooters in such a way that they can be easily repaired and providing repair and maintenance information is an important element in supporting the sustainability of e-scooters. Measures to limit user access to the workings of an e-scooter directly conflict with the goal of creating e-scooters that can be easily repaired and thus have an extended life. However, manufacturers do need to behave responsibly in the way they design their machines and in the information that they provide in the public domain. A responsible manufacturer is unlikely to want to publicise methods by which the top speed of their product can be easily increased, since this is likely to lead to premature failure and consequent warranty claims. But manufacturers should also be cautious in their design decisions to ensure that they do not facilitate tampering. This might include avoiding providing unrestricted access to the firmware of speed controllers, or providing easily accessible components that can be adjusted to change the maximum speed setting.

BS EN 15194:2017 and Regulation (EU) No 168/2013 both contain specific requirements for manufacturers to reduce the possibility that drivelines can be tampered with in ways that increase the maximum speed, power or torque of the machine. BS EN 15194:2017 specifically requires that manufacturers prevent access by users to software parameters affecting:

- Maximum speed with motor assistance
- Parameters that affect maximum speed
- Maximum gear ratio
- Maximum motor power
- Maximum speed of starting up assistance

BS EN 15194:2017 also further requires that reasonably foreseeable manipulations of the configuration of the vehicle are either prevented or compensated for; that alternate components e.g. batteries cannot be installed; and that the opening of relevant components is detectable through the application of seals. Thus easy modifications such as swapping the production battery for one of a higher voltage or changing the production wheels for larger ones to increase top speed should be mitigated via the design of the machine. However, there is anecdotal evidence that tampering of EAPCs is rife, which suggests that these measures may not be effective in practice.

Regulation (EU) No 168/2013 meanwhile is somewhat less prescriptive, but still requires manufacturers to prevent modifications that might increase power, torque or speed. The regulation also allows for modifications to the driveline under certain circumstances but specifies that such modifications must be specifically type approved and that these modifications may require the resulting vehicle to be type approved under another category.

We recommend that manufacturers of e-scooters be required to take reasonable precautions to ensure that speed limitation systems fitted to their machines cannot be easily defeated and that the maximum speed of a machine cannot be easily increased by, for example, fitting a swappable battery with a higher voltage or swapping the driven wheel for a larger one. In order to be truly effective this may require manufacturers to fit systems capable of measuring the speed of the e-scooter independently of the driveline, e.g. using GPS. However, it is unlikely to be possible to prevent all the potential methods that an ingenious tamperer might employ to defeat such a system via technical means alone.

12.6 Battery safety

We undertook a detailed study of battery safety standards and regulations and reviewed reports of fires resulting from batteries in micromobility devices (Section 9). We recommend that EN 17128:2020 should be updated to have the same requirement as EN 15194:2017 regarding the battery, and therefore the battery must comply with EN 50604-1:2016+A1:2021.

EN 50604-1 should be applied to the batteries of e-scooters, because the hazards are essentially the same as for road-legal e-mobility vehicles with removable lithium-ion batteries.

EN 50604-1 is the most complete and robust EU/UK standard applicable to light electric vehicle batteries. However, it also has some significant shortcomings. Our recommendations for updates to EN 50604-1 are summarised below:

1. EN 50604-1 should undergo a thorough revision following a review of errors and inconsistencies in the current version. For example, it refers normatively to other standards which have been withdrawn, or sections of other standards which do not exist.
2. EN 50604-1 should be updated to include requirements for production quality of the cells and the battery pack.
3. EN 50604-1 should be updated to include creepage and clearance distances.
4. The deep-discharge test in EN 50604-1 should be reviewed and updated, and a rationale should be provided.
5. EN 50604-1 should be updated to include an imbalanced charging test.
6. A thermal propagation requirement, similar to that in GTR20 / UNECE Reg100.03 should be considered for e-scooter batteries. However, the pass/fail criteria should be decided based on the hazards of thermal propagation in an indoor domestic setting.
7. EN 50604-1 should be updated to include a charging over-current test.

A revision to EN 17128:2020 to include EN 50604-1:2016+A1:2021, along with the recommended updates to EN 50604-1 is likely to be a lengthy process. We recommend therefore that DfT, or another appropriate government agency, initiates the creation of a set of best practice guidelines or Publicly Available Specifications (PAS) for the engineering of e-scooter batteries.

12.7 Hill climb ability and vehicle power

We conducted physical testing of a range of e-scooters and used models and engineering judgement to establish appropriate metrics by which the performance of e-scooters could be regulated (Section 8). We concluded that an acceleration limit is the best approach to separating the limit of hill climbing capability and the acceleration capability of the vehicle, instead of power. Our primary recommendation is that limiting the acceleration of an e-scooter is a more effective safety critical measure than implementing an arbitrary power limit.

We recommend that DfT implement the acceleration limit of 2 m/s^2, defined in BS EN17128:2020. Due to the significant variation of mass of the rider and vehicles (which will proportionally affect the acceleration) further consideration needs to be given to either standardise the test for a fixed system mass (vehicle plus rider), or set an absolute acceleration limit for all laden vehicle mass possibilities and allow manufacturers to engineer acceleration limiting solutions.

With an acceleration limit, combined with speed limiting functionality engineered into the vehicle along with vehicle mass limits, a power limit does not provide much additional value except to align with existing, outdated L-category vehicle regulations.

Several issues exist with continuous and peak power ratings, including:

- Maximum continuous rated power is not representative of any safety critical performance attribute of a vehicle. Limiting continuous rated power does not limit the performance of a machine in any meaningful way – instead it only limits the duration a vehicle can sustain a high output power. The real-world application of this for M- and L-category vehicles are long sustained gradients or sustained high speeds.
- For urban mobility, there are no 30-minute long hills or sustained high speed requirements.
- The safety critical vehicle performance attributes that are useful to limit are peak speed and acceleration. Typically, electric vehicles may accelerate (at their peak) for 10 seconds (less for urban mobility) – peak power is more representative of this. Better still is to limit vehicle acceleration and speed.

There are also issues with the UNECE Regulation 85 continuous power test:

- The current test for continuous rated power does not test for the maximum continuous rated power of a motor, but determines that a motor can run at the set power for a duration of time. When used as intended, “continuous rated power” is a metric that is intended to ensure that a motor can operate reliably at the power value specified by the manufacturer and does not place a cap on the maximum performance of a machine, as is the intention when a “maximum rated power” value is specified in regulation.
- The test only works in practice if it is in the interest of the manufacturer to achieve the highest possible value (higher power vehicles are normally more desirable when there isn’t a continuous rated power limit to meet).

12.8 Alternative arrangements for privately owned and shared devices

Throughout the study we considered whether different technical regulations should apply to privately owned and shared e-scooters. The ownership model of an e-scooter has no fundamental effect on its design although there are clear differences in the use cases of shared e-scooters and those that are owned and used by an individual. In particular, shared e-scooters tend to be more heavily built to cope with the rigours of being used more frequently and perhaps more importantly being left in the street where they may be subject to vandalism. Shared e-scooters also tend to have larger batteries to increase their range, compensate for their greater mass and thus reduce the frequency with which they must be charged. We took into account the possibility of a broad spectrum of ownership models that might exist in the future, for example, long term rental, membership schemes, community or workplace schemes and shared ownership. We also considered the evidence available regarding the way in which existing e-scooter rental schemes operate, both in the UK and further afield. We concluded that, while local authorities may wish to stipulate certain technical characteristics for the scooters used in open access rental schemes, and should continue to be allowed to do so via their licensing of those schemes, we saw no case to support different regulatory requirements for shared and privately owned e-scooters.

12.9 Sustainability, environmental impact and lifecycle

We undertook a desk-based study of the factors that affect the sustainability of e-scooter (Section 10). The key recommendations for sustainability and environmental impact relate to extending the total distanced travelled over the life of an e-scooter.

Driven by operational efficiencies and public perception, shared e-scooters operated by rental schemes have significantly extended life today compared to their early iterations, through improvements to product durability, servicing and maintenance schedules, repairability of vehicles and the availability of spare parts. A similar approach is required for private e-scooters.

Consideration should be made to create similar “right to repair” regulations for e-scooters that exist for other products in the EU’s Ecodesign for Energy-Related Products and Energy Information Regulations 2021, which includes ensuring availability of spare parts for at least 7 years, along with the availability of guidance and tools to undertake repairs. Recent additions to the list of product categories now include battery powered devices including mobile phones and tablets, with mandating swappable batteries proposed, however the safety of using replacement or repaired batteries should be prioritised over sustainability.

For both private and shared e-scooters, we recommend extending the mandatory warranty period to at least 2 years, with a longer warranty period considered. An extended warranty would encourage retailers to sell, and manufacturers to build, more durable and repairable e-scooters. Less durable or repairable (and therefore less sustainable) vehicles will not be viable to sell with an extended warranty due to the costs incurred from frequently replacing or repairing vehicles.

This may have an impact on the initial cost of the product to the consumer, and by extension the retailer and manufacturer, due to increased design, manufacturing and product support costs. However, it is envisaged that the implementation of these measures will lead to a higher quality product for consumers, with an improved lifespan and reduced environmental impact.

Further work is required to understand the implementation of a longer mandated warranty period, and how it would interact with possible Right to Repair regulations and the Consumer Rights Act (previously The Sales of Goods Act).

Concerns over the safety of replacement or repaired batteries should be prioritised over sustainability. It is stated, in the pre-amble of EU Regulation 2023/1542, paragraph (40), that: *"For repaired LMT batteries, the Commission will prepare rules on the safety of micromobility devices, building on experience at national and local levels of safety requirements, as announced in the communication of the Commission of 14 December 2021 on 'The new EU Urban Mobility Framework'."* However, there is no timeline provided for this activity.

In February 2022, CONEBI (Confederation of the European Bicycle Industry) issued a joint paper with ten other industry associations on the Removability and Replaceability of Portable Batteries. This recommended a more stringent definition of "readily replaceable" as follows:

*"A battery should be considered as readily replaceable where, after its removal from an appliance, it can be substituted by a **technically identical battery authorised by the manufacturer**, without affecting the functioning, safety or performance of that appliance. **A battery should always be exchanged as a whole. Parts of a complete, certified battery must not be replaced."***

The sections in bold above are notably absent from the final wording in Article 11 paragraphs 6 of EU Regulation 2023/1542.

The requirement to be able to remove individual cells has a major impact on the design and manufacturing of PLEV batteries, and in our view may have a detrimental effect on their safety.

Two-year warranty durations are provided in other European countries for the same products that have 12 month warranty durations in the UK.

12.10 Braking requirements

We reviewed the braking requirements of a range of standards (Section 3.2.2.4). The following recommendations are based on that review, testing conducted by TRL and WMG and our engineering judgement.

We recommend that, as a minimum, e-scooters of all types should be fitted with a mechanically or hydraulically actuated brake on each road wheel.

The braking system should be capable of bringing the machine to a complete halt. The system should under normal operating conditions be capable of decelerating the machine, at its maximum designed mass, at a rate of at least 3.5 m/s^2.

The braking system should incorporate redundancy of function such that any single component failure cannot leave the machine without any means to bring it to a halt. In practice this is likely to mean that two-wheeled machines at least will have a front and a rear brake, each operated by an independent hand lever. The system should be tested to demonstrate that these redundant systems are capable of producing sufficient braking effect independently. The German eKFV standard specifies a minimum of 44 % effectiveness for this test and we found no reason to deviate from this precedent.

For three or four-wheeled machines consideration should be given to the desirability of separating front and rear brake controls in this way and indeed a combined brake control that actuates both front and rear brakes together may be desirable, although such a system would need to be carefully engineered to ensure that redundancy was maintained if part of the combined system was to fail. M and N category vehicles do of course have a single combined control for front and rear brakes, but these are usually engineered to have a redundant (dual circuit) actuation system, which is capable of actuating at least two brakes in the event of a failure, and are always backed up by a secondary emergency brake (usually doubling as the parking brake), which can be used in the event of a complete primary system failure.

Consideration should be given to the desirability of allowing foot operated brakes, particularly for seated machines. For standing machines, foot operated brakes are likely to be undesirable, since they require the rider to balance on one leg while modulating the brake control, but for seated machines they seem perfectly acceptable and are common in motorcycles and other L-category vehicles. We therefore recommend that foot operated brakes are not permitted as part of the primary braking system for standing e-scooters, but can be permitted for machines with seats.

We recommend that systems which rely on pressing the mudguard onto the tyre should not be permitted as part of the primary braking system.

Regenerative braking can be a valuable asset in reducing the energy usage of electric vehicles, and as such should be encouraged. However, regenerative braking can be difficult to modulate and provides a variable retardation force which is dependent on battery charge level. We therefore recommend that regenerative braking should not be permitted as part of the primary braking system.

During our testing activities we came across one e-scooter which required the rider to pull back on the handlebars to actuate the brakes. This system appeared counterintuitive to operate and difficult to modulate effectively while maintaining balance under deceleration. While it is difficult to legislate for every potential edge case we recommend that regulations include a generic statement to the effect that the manufacturer must design braking and steering controls in such a way as to maximise the stability of the rider while operating the controls and thus ensure that braking and steering inputs can be modulated effectively without upsetting the balance of the rider.

12.11 Lighting and audible warning devices

We recommend that lighting, retro reflectors and audible warning devices be required according to BS EN 17128:2020. This requires a white front and red rear light, and a white front, red rear and either white or yellow side reflectors to be fitted. The audible warning device may be a horn or bell and must be operated by a control on the handlebars.

13 Suggestions for further work

In conducting this work and gathering evidence to formulate the recommendations we identified a number of remaining gaps which should be addressed through further work. These are as follows:

1. Investigation into the potential regulatory routes for approval of e-scooters and the associated advantages and disadvantages, including incorporation in the L-category (168/2013) and alternatives which specifically separate e-scooters from the motor vehicle regulations. One alternative could involve, for example, creation of a bespoke safety marking scheme along the lines of CE/UKCA.
2. Technical work to update current standards and/or develop new ones. As highlighted in this report, this should include:
    - Updating EN 17128:2020, in particular to incorporate more robust requirements for both structural overload and fatigue and to bring in the requirement to comply with EN 50604-1:2016+A1:2021 (battery safety).
    - Updating EN 50604-1:2016+A1:2021 – to address current shortcomings identified in this work.
    - Creating a set of best practice guidelines or Publicly Available Specifications (PAS) to provide interim cover for the gaps in structural integrity and battery safety in particular while the standards are updated.
3. Investigation into how to optimise the borders / marketplace enforcement approach of products in UK, in the context of e-scooters and other forms of micromobility.
4. Investigation to understand the implementation of a longer mandated warranty period to ensure longer product life, and how it would interact with possible Right to Repair regulations and the Consumer Rights Act (previously The Sales of Goods Act). This could include investigating similar approaches for other vehicles including Electric Assist Pedal Cycles.
5. Investigation into the most effective and suitable approaches for micromobility vehicle identification/registration.
6. Investigation into the suitability and definition of continuous and/or peak power ratings for limiting performance of e-scooters and other electric vehicles.
7. Investigation into the road user regulations required to optimise safety, sustainability and accessibility of e-scooters, in light of the work done here on technical regulations.

14 References

Almannaa MH, Ashqar HI, Elhenawy M, Masoud M, Rakotonirainy A and Rakha H (2021). A Comparative Analysis of E-Scooter and E-Bike Usage Patterns: Findings from the City of Austin, TX. *International Journal of Sustainable Transportation*, 15(7), 571–579, 10.1080/15568318.2020.1833117.

ATSDR (2016). [online]. [Accessed 11th December 2023]. Available from World Wide Web: Health Effects of Asbestos | Asbestos | ATSDR (cdc.gov)

Beard G, Guy I, Jenkins D, Wallbank C and Wardle A (2020). *Off-street e-scooter performance tests.* Crowthorne: TRL Limited.

Beard G, Lawson A and Jenkins D (2020). *Literature review to explore the impacts of e-scooter riding on physical activity and mental well-being.* Crowthorne: TRL Limited.

BBC News (2022). [Accessed 12th December 2023]. Available from World Wide Web: When and where can I ride an e-scooter legally? - BBC News

Boletín Oficial del Estado (2022). Manual of characteristics of personal mobility vehicles. Available from World Wide Web: https://www.boe.es/buscar/doc.php?id=BOE-A-2022-987

BSI (2017). BS EN 15194:2017. *Cycles – Electrically power assisted cycles – EPAC bicycles.* London, UK: British Standards Institution.

BSI (2020). BS EN 17128:2020. *Light motorized vehicles for the transportation of persons and goods and related facilities and not subject to type-approval for onroad use - Personal light electric vehicles (PLEV) - Requirements and test methods*. London, UK: British Standards Institution.

BSI (2020). PD ISO/TS 4210:2020. *Cycles – Safety requirements for bicycles*. London, UK: British Standards Institution.

Cano-Moreno JD, Reina JMA, Lanillos VDCP and Marcos MEI (2024). *Sensitivity of mass geometry parameters on E-scooter comfort: design guide*. Sensors, 24(2), 399.

Chaniotakis E, Johnson DT, and Kamargianni M (2023). *Emissions Savings Estimation of Shared E-Scooters: Analysis and Case Study.* University College London (UCL): London, UK

Confederation of the European Bicycle Industry et al, February 2022. Joint Position Paper: Removability and Replaceability of Portable Batteries (Art.11 of Batteries Regulation), https://rechargebatteries.org/wp-content/uploads/2022/02/Joint-Paper-on-Batteries-Draft-Regulation-Art.-11_FINAL.pdf

CPC and TRL (2022). *E-scooter policy and regulation review*. Milton Keynes: CPC Limited.

Destatis (2023). *Verkehrsunfälle: Kraftrad- und Fahrradunfälleim Straßenverkehr 2021*. Germany: Federal Statistical Office.

DfT (2022). *Reported road casualties Great Britain: e-scooter factsheet 2021*. London, UK: Department for Transport.

DfT (2023). *Reported road casualties Great Britain: e-scooter factsheet 2022.* London, UK: Department for Transport.

EPRS (2021). *New EU regulatory framework for batteries: Setting sustainability requirements*. Briefing paper PE 689.337.

E-scooter Clinic (2023). [online]. [Accessed 11th December 2023]. Available from World Wide Web: buy Handlebar Replacement for Xiaomi M365/Pro | Spare Parts \ Xiaomi Spare Parts (escooterclinic.co.uk)

ETSC and PACTS (2023). *Recommendations on safety of e-scooters*. London, UK: The Parliamentary Advisory Council for Transport Safety.

Eyers V, Parry I and Zaid M (2022). *In-Depth Investigation of E-Scooter Performance.* Crowthorne: TRL Limited.

FMSA (2019). *Ordinance on the participation of small electric vehicles in road traffic (Small Electric Vehicles Ordinance - eKFV).* Germany: Federal Motor Transport Authority.

Global Technical Regulation 20 (GTR 20), Electric Vehicle Safety (EVS), United Nations Economic Commission for Europe (UNECE), May 2018. https://unece.org/fileadmin/DAM/trans/main/wp29/wp29wgs/wp29gen/wp29registry/ECE-TRANS-180a20app1e.pdf

GOV.UK (2008). Supply of Machinery (Safety) Regulations 2008, 19/06/2021. https://www.legislation.gov.uk/uksi/2008/1597/contents

GOV.UK (2023a). Designated standards: machinery – notice of publication, 30 November 2023. Available from World Wide Web: https://www.gov.uk/government/publications/designated-standards-machinery

GOV.UK (2023b). [online]. [Accessed 11th December 2023]. Available from World Wide Web: https://www.gov.uk/government/publications/e-scooter-trials-guidance-for-local-areas-and-rental-operators/e-scooter-trials-guidance-for-local-areas-and-rental-operators

GOV.UK (n.d.). [online]. [Accessed 12th December 2023]. Available from World Wide Web: Electric bikes: licensing, tax and insurance - GOV.UK (www.gov.uk)

Guy I, Appleby J, Ball P, But B, Chowdhury S, Jenkins D … and Wardle A (2021). *Study on market development and related road safety risks for L-category vehicles and new personal mobility devices.* Crowthorne: TRL Limited.

Helmenstine, AM (2023). *"What Is the Density of Air at STP?,"* ThoughtCo. [Accessed 1st December 2023]. Available from World Wide Web: https://www.thoughtco.com/density-of-air-at-stp-607546

Himiway (2023). [online]. [Accessed 12th December 2023]. Available from World Wide Web: Best Choice for Heavier Riders: Himiway Fat Tire Electric Bikes (himiwaybike.com)

Hitchings J, Weekley J and Beard G (2019). *Review of current practice and safety implications of electric personal mobility devices.* Crowthorne: TRL Limited.

Hitchings J, Weekley J and Beard G (2021). *Update on current practice and safety implications of e-scooters.* Crowthorne: TRL Limited.

Janikian GS, Caird JK, Hagel B and Reay G (2024). A scoping review of E-scooter safety: Delightful urban slalom or injury epidemic? Transportation *Research Part F: Traffic Psychology and Behaviour, 101, 33-58.*

Kawajiri, K. and Sakamoto, K., 2022. *Environmental impact of carbon fibers fabricated by an innovative manufacturing process on life cycle greenhouse gas emissions. Sustainable Materials and Technologies, 31, p.e00365*

Levy, 2023. *Understanding the Lifespan of Electric Scooter Tires.* Available from World Wide Web: https://www.levyelectric.com/resources/understanding-the-lifespan-of-electric-scooter-tires (accessed 11.22.23).

MCIA (2019). *The route to tomorrow's journey – Micromobility regulation: A discussion document.* Coventry, UK: MCIA.

MCIA (2021). *Micromobility (e-scooter) L0e & L1e-C (electric moped/scooter) regulatory requirements.* Coventry, UK: MCIA.

Ministry of Infrastructure and Water Management (2022). *Dutch framework for Light Electric Vehicles (LEV).* Netherlands: Ministry of Infrastructure and Water Management.

MMfE (2023). Incident data involving shared e-scooters.

NHS (2022). [online]. [Accessed 11th December 2023]. Available from World Wide Web: Part 4: Trends - NHS Digital

Novotny A, Mollenhauer M and White E (2023). *E-scooter design: Safety measures for next gen scooter*. Available from World Wide Web: http://hdl.handle.net/10919/115362

Ohneseit S, Finster P, Floras C, Lubenau N, Uhlmann N, Seifert HJ and Ziebert C (2023). Thermal and Mechanical Safety Assessment of Type 21700 Lithium-Ion Batteries with NMC, NCA and LFP Cathodes–Investigation of Cell Abuse by Means of Accelerating Rate Calorimetry (ARC), Batteries 9 (5), 237. https://www.mdpi.com/2313-0105/9/5/237

PACTS (2022). *The safety of private e-scooters in the UK*. London, UK: The Parliamentary Advisory Council for Transport Safety.

PACTS (2023). *Comparing police and hospital e-scooter casualty datasets: A review of the under-recording of e-scooter casualties in the UK*. London, UK: The Parliamentary Advisory Council for Transport Safety.

Paudel M and Yap FF (2021). Front steering design guidelines formulation for e-scooters considering the influence of sitting and standing riders on self-stability and safety performance. *Proceedings of the Institution of Mechanical Engineers, Part D: Journal of Automobile Engineering, 235, 2551-2567.*

Pure Electric (2023). [online]. [Accessed 19th December 2023]. Available from World Wide Web: What is the weight limit for a Pure Electric E-Scooter? – Pure Electric

Regulation (EU) 2023/1542 of the European Parliament and of the Council of 12 July 2023 concerning batteries and waste batteries, amending Directive 2008/98/EC and Regulation (EU) 2019/1020 and repealing Directive 2006/66/EC, European Union, 28 July 2023 https://eur-lex.europa.eu/legal-content/EN/TXT/?uri=uriserv%3AOJ.L_.2023.191.01.0001.01.ENG&toc=OJ%3AL%3A2023%3A191%3ATOC https://eur-lex.europa.eu/eli/reg/2023/1542/oj

Roche, Schinkel, Storey, Humphris & Guelden, 1998. *Speed of Light.*

Siebert FW, Ringhand M, Englert F, Hoffknecht M, Edwards T and Rötting M (2021). Braking bad – Ergonomic design and implications for the safe use of shared E-scooters. *Safety science, 140, 105294*.

Subramanian R (2010). *Strength of Materials*: Oxford University Press.

Transport Committee (2020). *E-scooters: Pavement nuisance or transport innovation?* London, UK: House of Commons, Transport Committee.

UNECE (2022). Regulation No. 100 Rev.3, Uniform provisions concerning the approval of vehicles with regard to specific requirements for the electric power train, United Nations Economic Commission for Europe (UNECE), March 2022

University of Bristol (2020). *Can e-scooters contribute to sustainable urban transport in Bristol*

United Nations Economic Commission for Europe (UNECE), March 2022. *Regulation No. 100 Rev.3, Uniform provisions concerning the approval of vehicles with regard to specific requirements for the electric power train.* https://unece.org/transport/documents/2022/03/standards/regulation-no-100-rev3

Wardle A and Beard G (2020). *Review of national and international e-scooter standards and regulations*. Crowthorne: TRL Limited.

Wilford R, Wardle A, Jenkins D and Beard G (2020). *Safety considerations for on-road trials of e-scooters.* Crowthorne: TRL Limited.

Yang H, Ma Q, Wang Z, Cai Q, Xie K and Yang D (2020). Safety of micro-mobility: Analysis of E-Scooter crashes by mining news reports. *Accident Analysis & Prevention, 143*, 10560

Appendix A Literature review search terms

Topic	*International* construction standards*	*Research that advises construction standards*	*Collision and defect reports*
Search terms	e-scooter electric scooter **AND** Construction Design Engineering Manufacture Production Technical **AND** Standard Legislation Regulation Law Specification Requirement Typology Guidance Advice **additional search terms to explore international literature will also be used where necessary to explore evidence; this would include using specific countries (e.g. France, Germany) as search terms*	e-scooter electric scooter **AND** Size Dimensions Width Height Weight Mass Geometry Wheel Tyre Handlebar Light Indicator Audible warning Horn Bell Motor Battery Brakes **AND** Design Standard Legislation Regulation Law Specification Requirement Typology Guidance Advice Recommendation Safety Risk Danger Hazard Cost Price Outcome Impact	e-scooter electric scooter **AND** Collision Crash Accident Incident Injury Defect Flaw Fault Failure Issue **AND** Data Statistics Figures Numbers Frequency Rate Occurrence Outcome Impact Result Circumstances Conditions Situations Scenarios

Appendix B Interviews with disabled people – Topic guide

The broad purpose of this discussion is to understand the needs and challenges of disabled people using and encountering e-scooters. The discussion will focus primarily on the physical design of e-scooters and the potential technical regulations that might apply to them. This in turn is to help the Department for Transport define the technical requirements for e-scooter regulations.

We anticipate the discussion to last around 45 minutes.

With your permission we will record the session. Recordings will only be used to support with notetaking. These will not be shared with anyone outside of the project team and will be deleted at the end of the project.

If you require subtitles, you can turn these on by going into the 'More' menu > Language and speech > Turn on live captions.

Any quotes we use from these discussions will be completely anonymised. There will be no way to link any quotes to a specific individual.

Please remember that there is no right or wrong answers. We are interested in to know about your thoughts and experiences in your own words. Please be honest in your response.

You are free to leave the call at any point without giving a reason, but please let us know if you need a break at any point of time.

Topics and questions used in interviews:

1. Introduction

Objective: To build rapport and get to know the group.

Prompt: Introductions,overview of the session

2. Attitudes towards e-scooters

Objective: Explore people's current or future behaviours and perceptions towards e-scooters.

Question: Do you think the ready availability of legal e-scooters will make it easier or harder for you to get around?

Prompt: Do you feel that they are a useful addition to the transport system?

Prompt: Do you feel that sharing public spaces with them creates new risks for you?

3. Use of e-scooters by disabled people

Objective: Explore the potential use of e-scooters by disabled people.

Question: Do you think of yourself as a potential e-scooter user?

P*rompt: If non-rental e-scooters were legal to use, would you want to own one?*

P*rompt: Have you ri*dden a rental scooter? What was your experience?

Question: Imagine personal e-scooters were legal to use. What do you feel could be done to improve e-scooter design to better meet your needs as a potential user?

Question: What design features would make it easier/possible for you to use an e-scooter?

*Prompts: A seat, having more than two wheels, having the facility to carry…[*shopping bag, oxygen cylinder, child etc.]

Question: If you had (have) to use a mobility aid, like a mobility scooter or a wheelchair, do you think you might choose to use an e-scooter instead?

Question: Currently the rules that apply to mobility scooters and powered wheelchairs allow them to be used on the pavement and inside buildings. It is unlikely that e-scooters will be allowed to operate in the same way. Would your choice to use an e-scooter rather than a device designed specifically for disabled people be affected by how and where you were allowed to use those devices?

Further info: Mobility scooters can be used on the pavement and inside buildings at a maximum speed of 4 mph, e-scooters will almost certainly be banned from those spaces unless they are fitted with some system to limit their speed in specific locations.

Prompt: Mobility scooters have a maximum speed of 8 mph on the road, e-scooters will almost certainly have a higher speed limit – perhaps 12-15 mph.

4. Interaction with e-scooters as a road user

Objective: Explore how e-scooters can be designed to minimise the risk they pose to other road users.

Question: Does your disability specifically affect how you interact with e-scooters as another road user (e.g. pedestrian or driver?)

Question: What are your experiences of encountering e-scooters in public places?

Prompt: Have your experiences been broadly positive, negative or neutral?

Question: Have you been made to feel, or actually put, at risk by e-scooters being used in public places?

Question: Was this risk created because of the way the rider behaved or because of the way the e-scooter is designed?

Question: What do you feel could be done to improve e-scooter design to improve your interactions with them?

Prompts: more audible warning of their presence (constant noise generator, bell/horn etc.), more visual warning of their presence (lighting, reflective materials, colours etc.), making them slower by design (speed limiters)

5. Debrief

Objective: Summarise key points covered and provide additional detail on purpose of this work

Discussed your views, needs and challenges regarding e-scooters. Highlight any key talking points raised. Ask if there are any final points anyone wants to add on anything that's been covered.

Detail how the findings of this work will be used.

Prompt: We will explore key themes raised from these group discussions; these will be incorporated into a larger report which will contribute to any updates in the technical standards and construction regulations of e-scooters.

You will soon receive your compensation for taking part.

Any final questions on anything

Technical research into construction standards for e-scooters

The aim of this project was to provide guidance to the DfT on certain aspects of technical regulations that may in future be applied to e-scooter if their use in public places is to be made legal. They key themes of this investigation were the safety, sustainability and accessibility of e-scooters.

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