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European Commission

Study on market development and related road safety risks for L-category vehicles and new personal mobility devices

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TRL

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Directorate C — Sustainable Industry and Mobility
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1. Executive summary

1.1. Objectives of this study

TRL was invited by the European Commission to undertake a study into the market development and safety of personal mobility devices (PMDs) and L-category vehicles. The objectives of this study were:

1. to provide an inventory of the various types of personal mobility devices available on the market,
2. to provide a detailed analysis of the market and the influence of the existing legislations at EU and national level,
3. to provide a collection and evaluation of available data and information on accidents involving personal mobility devices,
4. to assess the current use and the safety aspects related to the road circulation of personal mobility devices not covered by EU type-approval,
5. and to provide recommendations with regard to minimum safety technical requirements they would have to fulfil and the traffic rules, i.e. use and behaviour rules, that they could be subject to.

1.2. Scope of this study

The following vehicle types were deemed to be within the scope of this investigation:

- Stand-up and seated e-scooters (Figure 1)
- Electrically assisted pedal cycles including electrically power assisted cycles (EPACs), those currently within the scope of Regulation (EU) No 168/2013 (Figure 2) and those intended for carrying commercial cargo (Figure 3)
- Self-balancing vehicles including self-balancing personal transporters and hoverboards (Figure 4)
- Electric unicycles (Figure 5)
- Electric skateboards and 'One-wheel' boards (Figure 6)

Excluded from the scope of this investigation were:

- 'Toys' intended for use only by children
- Devices intended for use only by those with a physical disability
- Devices with no capability to carry people (e.g. cargo robots)
- Pedestrian controlled vehicles, i.e. vehicles in which the operator walks with the vehicle rather than riding on or in it
- Non-land vehicles (e.g. jet-skis, passenger carrying aerial vehicles etc.)
- Vehicles specifically designed for use off-road (e.g. dirt-bikes)
- Vehicles that are wholly powered by the rider/driver (e.g. non-assisted bicycles)

For the purposes of this investigation all vehicles within the scope of the study were considered to be PMDs.

Figure 1: Standing (L)[1] and a seated e-scooter (R)[2]

Figure 2: An EPAC (L)[3] and a type approved cycle designed to pedal in L1e-B (R)[4]

Figure 3: An electrically assisted cargo bicycle[5]

[1] Source: Nellafoto via Pixabay (license free) Scooters Wheels Transportation - Free photo on Pixabay
[2] Source: Polvadis via Wikipedia under Creative Commons Attribution-Share Alike 3.0 license File:GiGi Electric Scooter.jpg - Wikipedia
[3] Source: Fbenedict via Pixabay (license free) Ebike Pedelec Bike - Free photo on Pixabay
[4] Source: MyStromerAG via Wikipedia Creative Commons Attribution-Share Alike 4.0 International license File:Stromer ST2.png - Wikimedia Commons
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Figure 4: Self balancing personal transporters (L)[6] and a 'hoverboard' (R)[7]

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Figure 6: An electric skateboard (L)[10] and a 'one-wheel' board (R)[11]

[6] Source: Pixel4Free via Pixabay (license free) Budapest Hungary Segway - Free photo on Pixabay
[7] Source: Schäferle via Pixabay (license free) Hoverboard E-Board Wheels - Free photo on Pixabay
[8] Source: Airwheel via Pixabay (license free) Mobility Air-Wheel Monocycle - Free photo on Pixabay
[9] Source: JACLOU-DL via Pixabay (license free) Transport Electric Unicycle - Free photo on Pixabay
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[11]Source: Elvert Barnes via Flickr under Creative Commons Attribution-ShareAlike 2.0 Generic license Skateboarder1.NoMa.WDC.17July2019 | One Wheel Skateboarder a… | Flickr

1.3. Regulatory background

The technical requirements and approval mechanisms for PMDs are governed by two key pieces of EU legislation. The first is Regulation (EU) No 168/2013 which defines the L-category of two- and three-wheeled vehicles and quadricycles and details the manner in which these vehicles are approved for sale on the EU market and for use on roads in EU Member States. The second is Directive 2006/42/EC (known as the Machinery Directive) which sets out the essential health and safety requirements and the approval and certification methods applying to 'machinery' offered for sale with the EU. Currently some PMDs, as defined above, fall within the scope of Regulation (EU) No 168/2013 and are type-approved as 'vehicles', e.g. powered cycles in sub-category L1e-A, while others e.g. electrically power assisted cycles (EPACs) are specifically excluded from the scope of the regulation and are instead treated as 'machines' and approved for sale under the Machinery Directive.

While approval under Regulation (EU) No 168/2013 carries with it the automatic right to be placed into service in all EU Member States and thus to be used on the roads of those states, certification under the Machinery Directive carries no such rights. PMDs that are outside of the scope of Regulation (EU) No 168/2013 are therefore reliant on the stipulations of the national regulations of each Member State for their permission to be used on the public road (and other public spaces including footways and cycle lanes). This lack of harmonisation has led to significant disparities between what is and is not allowed to be used on the roads and the technical standards with which PMDs are expected to comply between different Member States. This lack of harmonisation has been thrown into particularly sharp focus by the sudden and rapid development of e-scooter rental schemes which have seen large scale adoption in some Member States but have been prevented from starting in others whose national regulations do not permit such 'machines' to be used on the road. For the consumer the situation is complicated by the fact that it is legal to sell PMDs that are not legal to use on the roads of the Member State in which they live. Consumers may thus unwittingly leave themselves open to prosecution by using a 'machine' that is not legal to use on the roads of a particular Member State.

1.4. Survey of PMDs available for sale in the EU

The PMD market is rapidly growing in diversity and includes a broad range of vehicles that vary significantly in their configuration, size, number of wheels and operating principles. The common feature that they all share is that they are powered either completely or in part by small electric motors. In order to address the first objective of this study TRL undertook a market review to capture the breadth of the diversity of vehicles that are for sale in the EU and the functional safety features that are found in each type of vehicle. The findings of that review are described in detail in section 5. This review was not intended to produce a definitive catalogue of every make and model of PMD available in the EU, but instead to illustrate the diversity of what is available. As part of the review we deliberately did not seek to make any judgement around whether or not the products found would currently be legal to use on the road in all Member States. However, we did come across some instances of vehicles that were erroneously described as being legal to use on the road in some Member States, where in fact they were not. For practical reasons we have grouped the vehicles found in the market review according to their most prominent physical characteristics. These groupings may overlap in places with existing sub-categories within the L-category, but where this was the case, we chose not to exclude vehicles that do not fully meet the technical regulations for that sub-category. In order to limit the scope of our market review we deliberately excluded vehicles that were already type-approved as mopeds in L1e-B, although we did include cycles designed to pedal in L1e-B and we also excluded anything that would otherwise fall into a higher sub-category, whether it was type approved or not.

We assessed each of the vehicles found against the following series of functional safety headings:

- Maximum continuous or rated power,
- Maximum device design speed and cut-off speed of auxiliary propulsion,
- Dimensions: width, length, height, seat height and ground clearance,
- Load platform dimensions and minimum volume that can be carried,
- Laden and unladen mass,
- Maximum rider mass,
- Type of propulsion and engine/battery capacity,
- Number of axles and wheels,
- Number of seating positions / occupants,
- Anti-tampering measures,
- Dimensions,
- Braking,
- Steer-ability,
- Stability,
- Lighting and conspicuity,
- Audible warning device,
- Electrical safety,
- Rearward visibility,
- Device structure integrity,
- Stands,

These assessments were based solely on the information that was available online from retailers and manufacturers – no physical assessments were made of any vehicle nor were any checks made to verify the accuracy of the information. Our findings from these assessments and our commentary on the implications of these findings are also presented in section 5. The raw data on which these assessments are made are available in a separate electronic appendix.

1.5. The PMD market in the EU

In order to fulfil the requirements of the second objective we collected market data from the relevant industry bodies, national and local authorities, and companies operating hire schemes. Here we found a diversity of approach between the different PMD sectors, with data on pedal cycle derived vehicles readily available and well collated by pan-European trade associations, while data on e-scooters had to be sought from national and local authorities and the companies operating hire schemes, and data on other types of PMD e.g. self-balancing vehicles, were not available at all. This reflects the maturity of these markets and the historic relationship between electrically assisted bicycles and the much older conventional bicycle industry and the relative novelty of other types of PMD. Our findings on the current market performance of PMDs can be found in Section 6. In Section 8 we have prepared a series of case studies in which we illustrate the effects of regulation at an EU and national level on EPACs, cycles designed to pedal in L1e-B, personal light electric vehicles including e-scooters and self-balancing vehicles, and electrically assisted cargo bikes.

The available data suggest that currently the PMD market is dominated by pedal cycle derived vehicles which all have powertrains in which the rider is provided with pedals through which they can partially or entirely power the vehicle alongside an electric motor which provides assistance. These pedal cycle derived vehicles are currently categorised into:

- EPACs which have a maximum assistance speed of 25km/h and a maximum continuous motor output of 250W,

- Powered cycles in L1e-A which also have a maximum assistance speed of 25km/h and a maximum motor power of 1,000W, and

- Cycles designed to pedal in L1e-B which have a maximum assistance speed of 45km/h and a theoretical maximum motor power of 4,000W but are also restricted to a maximum of 4x the human power input.

EPACs are specifically excluded from the scope of Regulation (EU) NO 168/2013 and are not type-approved. They are however subject to a European standard (CEN15194), which has been made legally binding by some but not all EU Member States. The other two groups of vehicles fall within the scope of Regulation (EU) No 168/2013 and are subject to type approval. The existence of these three categories of ostensibly very similar vehicles that are subject to distinctly different type-approval, and consequently road circulation, regulations permit some observation to be made on the apparent effects of regulations on the market. Clearly markets are complex systems and it is never possible to fully isolate the effect of a single factor in the market performance of a particular group of vehicle; marketing effort by a manufacturer, cultural norms, the availability of suitable infrastructure and a whole range of other factors may play a part in the market growth of a particular type. However, it is evident that the non-type approved EPACs have historically enjoyed a much greater market share than their type-approved counterparts in L1e-A and B. From a technical perspective there are few if any fundamental differences between these groups. From a performance perspective clearly the cycles designed to pedal in L1e-B have an advantage over both EPACs and L1e-As in that they have a much higher permitted maximum speed. But that performance advantage has not resulted in better sales, with sales of EPACs exceeding those of cycles designed to pedal in L1e-B by a factor of almost 100-1. Meanwhile powered cycles in L1e-A are effectively absent from the market. The primary driver of this market behaviour is likely to be the much higher barriers to ownership imposed on the type-approved vehicles. To be clear, while manufacturers find the type approval process somewhat onerous and costly, it is not the type-approval process itself that is depressing the market for type-approved pedal cycles. Instead it is the automatic imposition on these vehicles of road circulation rules that are consistent with those applied to other L-category vehicles that is likely to make them less attractive to users. These rules, including the requirement to hold a driving license, register the vehicle with the national authorities, wear an approved motorcycle helmet to have vehicle insurance etc. only apply to the types in the L-category and not to EPACs, which are subject to the same rules as conventional bicycle.

1.6. Cost benefit analysis

We have used the example of the three groups of electrically assisted bicycle described above to help make predictions on the likely reaction of the market to future regulatory schemes that may be applied to other types of PMD. In Section 10 we present a cost benefit analysis in which we compare the possible effects of two scenarios:

1) a scenario which draws all PMD types into the scope of Regulation (EU) No 168/2013 and consequently subjects them to the same road circulation regulations as other L-category vehicles, against;

2) a scenario in which all PMDs are subject to a technical and road circulation regulatory regime analogous to EPACs.

We have assumed that the latter approach would lead to substantial and sustained market growth, as has been seen with EPACs, while mandatory type approval would lead to market growth more closely aligned with that of cycles designed to pedal in L1e-B. We have assumed that the bulk of the growth in new types of PMD will be concentrated in standing e-scooters and we have used the available (albeit limited) data to predict the likely mode shift that would result from a growth in this area. We have assumed that the overall number of journeys taken does not increase as a result of greater access to PMDs as there are currently no data available to suggest otherwise. The estimated casualty figures and the associated costs we quote in Section 10 are intended only to illustrate our commentary and should not be treated as accurate predictions. For the purposes of the model we have assumed that the risk of being involved in a fatal collision per journey is the same for all PMD types as currently there is no conclusive data to prove otherwise. This should not be taken as an assertion that specific technical regulations for different types are unnecessary but simply that at present there is insufficient data to draw firm conclusions on the relative safety of novel PMD designs. We have also assumed that the existing road infrastructure is not modified to take account of a growth of PMD use. In reality increasing access to infrastructure that is dedicated to light weight, low speed vehicles is likely to have a positive effect on casualty numbers, but we consider the design of infrastructure to be outside the scope of this study.

The ITF (2020) reported that the use of PMDs results in approximately 40 fatalities per billion trips, while the equivalent risk for bus passengers is 15 per billion trips, for pedestrians is 20 per billion trips, for car occupants is 50 per billion trips and for motorcycle and moped users is 425 per billion trips. These figures include fatalities affecting the users themselves and others who they may injure while using their vehicles. This difference in relative risk between different modes of transport is the key factor in our cost benefit analysis. The manner in which mode shift occurs therefore is crucial to the safety effect of increasing numbers of PMD journeys. Broadly, taking pedestrians and bus passengers and turning them into PMD users has a negative effect on safety, while taking car occupant and turning them into PMD users has a positive effect and taking motorcyclists or moped users and turning them into PMD users has a strongly positive effect. However, we have made no assessment of any other potential effect of increased PMD use beyond its immediate effect on casualty rates from collisions. It is entirely conceivable that enabling mode shift to small, lightweight electric vehicles may have a range of other benefits including improvements in air quality that may have a much broader health effect, or reductions in the contribution of transport to carbon emissions and climate change. It is also possible that using a PMD may have other health benefits for users, which have been shown for cycling, but are yet to be proven for new types of PMD. We have also not taken into account any effect arising from the current Covid 19 pandemic, which is likely to have an effect on mode shift – away from public transport, and also represents a potentially significant risk factor for passengers of shared vehicles.

1.7. Stakeholder engagement

As part of this study we also undertook a large-scale stakeholder engagement exercise in which we invited 730 stakeholders including PMD manufacturers, distributors, retailers, regulators, local and national authorities, user groups, industry associations and representatives of adjacent industries to participate. The purpose of this exercise was two-fold, firstly we wanted to collect detailed information on technical, economic and regulatory topics, which we did via bilateral interviews and correspondence; secondly we wanted to gauge the opinion of stakeholders on the content of potential future technical and road circulation regulations for PMDs and the mechanisms by which they should be applied. This second element of our stakeholder engagement was done via a three-step Delphi panel process in which we first sought suggestions for potential technical and road circulation regulations via an online survey, we then invited stakeholders to rate the practicality, effectiveness and economic consequences of these suggestions in a second online survey, then finally conducted two online workshops in which we invited stakeholders to discuss the measures that had been put forward. This process is described in greater detail in Section 9.

The key findings from the Delphi panel were that stakeholders were broadly supportive of the idea of harmonising regulations for PMDs across the EU, but felt that specific technical regulations were required for PMDs with distinctly different characteristics. The primary distinctions made were between using characteristics indicative of risk, e.g. speed, rather than the physical configuration of the vehicle, e.g. the number of wheels. On road circulation regulations the consensus was broadly towards aligning requirements for PMDs with those that currently apply to pedal cycles. This was however to some extent conditional on matching the performance of PMDs with pedal cycles, i.e. by limiting their maximum speeds, physical dimensions and mass.

1.8. Safety of PMDs in the EU

In order to meet the third and fourth objectives of this study we examined the available academic studies and collision data (section 7) on the safety of PMDs. As in several other sections, these data are dominated by information relating to pedal cycle derived types, reflecting the prevalence and maturity of these types in the market rather than their level of risk. Very few Member States currently record PMDs as a separate category in their national collision statistics. Germany and Belgium are notable in that they have been recording collisions affecting EPACs and cycles designed to pedal in L1e-B separately for several years. Some German states and France have recently begun to record collisions involving e-scooters separately. Section 7 summarises and reviews the data available from these sources. While there are a number of observational studies that concentrate on injuries resulting from collisions involving e-scooters, we didn’t find any studies that took an epidemiological approach to the risks associated with PMDs that aren’t derived from pedal cycles. There are several studies that take an epidemiological approach to the safety of electrically assisted bicycles in their various forms. These are largely in agreement that, once increased usage is taken into account, the risk of riding an EPAC is no different to the risk of riding a conventional pedal cycle. However, we must of acknowledge that the risks associated with the use of pedal cycles remains significant, accounting for around 2,000 fatalities per year in the EU.

1.9. Regulatory options

In Section 3 we propose a variety of regulatory options that may be applied at an EU level in order to harmonise the technical, and by association road circulation, regulations for PMDs. We have proposed five options, although in reality a great deal more nuance would be required before committing to legislation. Briefly those options are:

1. Include all PMDs within the scope of Regulation (EU) No 168/2013,

2. Exclude from the scope of Regulation (EU) No 168/2013 any PMD with a maximum speed less than 25km/h,

3. Exclude from the scope of Regulation (EU) No 168/2013 any PMD with a maximum speed less than 30km/h,

4. Exclude from the scope of Regulation (EU) No 168/2013 any PMD with a maximum motor power less than 1,000W, and

5. Devise a dedicated system for the harmonised approval of PMDs that is separate from both Regulation (EU) No 168/2013 and the Machinery Directive.

Of these we feel that there is no evidence to support adoption of the first option and have included it only to show that it has been considered and dismissed. By themselves, options 2, 3 and 4 would serve to simplify the criteria for exclusion from the scope of Regulation 168/2013 and would thus provide design freedom for new types of PMD without the requirement to comply with type-approval regulations, but would not of themselves resolve the issue of harmonising the regulation of PMDs across the EU. Option 5, which may be combined with options 2 or 3 and 4 would provide a system for technical regulation which is outside both the Machinery Directive and Regulation (EU) No 168/2013. This system would be tailored to the needs of the PMD industry and would combine elements of self-certification similar to those used under the Machinery Directive with targeted testing and technical oversight from independent testing and verification services. In our view this new system for the regulation and approval of PMDs would provide the flexibility necessary to support innovation in this rapidly evolving sector, while maintaining technical standards and road safety.

1.10. Important findings and recommendations

In Section 4 we highlight the important findings of our work and make a number of recommendations regarding road circulation rules for PMDs and possible amendments to Regulation (EU) No 168/2013. We discuss possible amendments to the way in which the L1e-A sub-category is defined and the potential benefits this might have to the regulation of cycles designed to pedal, currently in L1e-B and cargo bikes. In particular we recommend raising the speed limit of the L1e-A category to 45km/h while retaining the 1,000W motor power limit, thus creating a sub-category that is dedicated to higher speed PMDs, including cycles designed to pedal, which is separate from the moped category. Our principle recommendation around road circulation rules for PMDs is that they should be closely aligned to those for pedal cycles.

In this section we discuss the information that has been shared with us by stakeholders and our own observations of the market and safety data available to conclude that EPACs should not be subject to regulations that are more strict than those already in place. We also discuss the phenomenon of tampering to raise the maximum speed of EPACs and conclude that type-approval would not be an effective mechanism to combat this practice, but that there are steps that manufacturers, dealers, maintenance organisations and regulators could take to reduce its prevalence.

Currently there is a lack of uniformity in the way collisions involving PMDs are recorded and reported by national authorities, which makes the development of a proper understanding of the risk profile of these vehicles difficult. We make recommendations for the way in which collisions involving PMDs are recorded and reported. In particular we outline the importance of separating collisions involving PMDs from those involving other types in order to allow the safety of these new types to be monitored effectively.

During the course of our investigation we identified some issues that were affecting vehicles intended primarily for use off-road and vehicles intended solely for use by those with a physical disability. Both of these groups of vehicles are specifically excluded from the scope of Regulation (EU) No 168/2013 and are consequently regulated by Member States under national regulations. In the case of vehicles intended primarily for use off-road we were alerted to the possibility that the sale and use of these vehicles could pose a safety risk to those using off-road tracks and trails, that the use of these vehicles could result in landowners seeking to impose restrictions on electrically assisted mountain bikes and that they may be acting as a conduit for the sale of vehicles which are illegally used on the road. We were alerted to a number of concerns around the safety and use of vehicles intended specifically for the use of those with a physical disability. In particular we were informed that one Member State was suffering over forty fatalities per year involving the use of these vehicles. While outside of the scope of this investigation we highlight these issues as being a cause for concern and a potential area for further investigation.

2. Introduction

Currently there are no EU harmonised regulations specifically intended for PMDs that are not derived from pedal cycles. Electrically assisted pedal cycles with assistance speeds of greater than 25km/h, or with motor powers of greater than 250W fall within the scope of Regulation (EU) No 168/2013 and are consequently subject to type-approval. Electrically assisted pedal cycles with powers or assistance speeds lower than these limits are specifically excluded from the scope of Regulation (EU) No 168/2013 and are instead subject to self-certification by manufacturers against the CEN standard 15194. The market for this latter category of vehicles is two orders of magnitude greater than for their type approved counterparts and there is a widespread belief that this is at least in part due to the higher cost of production and consequently purchase of a type approved vehicle. However, the reasons for the relative success of non-type approved vehicles are rather more complex than the simple cost differential associated with type-approval. As well as being slightly more expensive to buy, type approved cycles designed to pedal in the L1e-A and B sub-categories are subject to a much more stringent set of road circulation regulations, which typically require their riders to hold a licence, insurance, be above a certain minimum age and wear an approved motorcycle helmet, while their non-type approved counterparts have none of these restrictions. We must be careful then to ensure that the reasons for the relative success of non-type approved electrically assisted bicycles are not mis-attributed entirely to the technical regulations to which they are subjected, particularly as we attempt to develop a regulatory approach to newer forms of vehicle.

Clearly there is a requirement to ensure that vehicles that operate in public spaces comply with some minimum technical standards to ensure that they do not pose an undue risk to either their riders or those around them. The regulatory mechanisms by which these minimum standards can be enforced fall into two distinct approaches; national or international standards which are adopted by manufacturers and importers and are effectively self-administered, or national or international regulations which are imposed on manufacturers and importers which are enforced by statutory authorities. In either case the technical requirements to which the vehicles are subject may be identical. However, the inclusion of a particular vehicle type into existing regulations, e.g. Regulation (EU) No 168-2013, brings with it the possibility of unintended restrictions or requirements being applied to vehicles for which those regulations were not originally designed. Regulation should as far as possible be proportionate to risk while also supporting economic productivity and environmental sustainability.

Until relatively recently the only Personal Mobility Device (PMD) in use in any great numbers were pedal bicycles. While there has always been a diverse array of lightweight vehicles available, they have almost always had only niche appeal. That situation changed significantly with the advent of commercially available electrically assisted bicycles which first came to the market in the 1990’s. While their penetration into the market was initially quite slow, and focused primarily towards encouraging less physically fit cyclists to participate, they have in the last ten years grown into a significant market sector supported by a rapidly growing industry comprising traditional cycle manufacturers and new entrants to the market.

The last five to ten years has seen a rapid diversification of PMDs. The primary characteristic of this diversification has been a move away from the classical pedal cycle form to a variety of wholly new or re-imagined vehicle configurations. The primary technological enabler of these new developments has been the widespread commercialisation of new battery technologies which has enabled the production of lightweight electric drive trains at relatively modest cost. These new drive trains, combined with cheap, solid-state digital control systems, have permitted the development of a whole new type of self-balancing vehicle, which rely entirely on their motor control electronics for both their stability and control. This new concept has been realised in a variety forms, including one and two-wheeled vehicles.

The advent of readily available electric drive trains has also led to the reimagination of some classical vehicle forms. Most notable amongst these being the powered stand-up scooter, which have been available with small petrol engines for many years, but which now, equipped with quiet, clean, electric motors, have recently seen mass adoption in many cities.

These technological changes have been accompanied by changes to the ownership model for some types of PMD, themselves driven by the widespread adoption of smart-phones with their ability to provide instant online registration and payment. This has led to the creation of large fleets of PMDs that can be rented for short journeys which, crucially, do not have to start and end at the same location. Additionally, the drive towards lower carbon transport modes has led to the development of a range of subsidised leasing and hire-purchase schemes for PMDs - most commonly bicycles.

While these technological and commercial developments have been largely positive in that they have promoted the adoption of active or lower emission transport modes, the rapid changes observed have outpaced developments in the frameworks for both the technical and road-circulation regulations. This has led to a lack of harmonisation in the approaches taken by Member States and a large and rapidly growing fleet of vehicles that are in use on the road but are effectively outside of the current EU regulations, or in some cases actually illegal.

This report offers an overview of the PMD market and seeks to map out the broad spectrum of PMDs now available. Analyses have been made of the regulatory regimes that exist in the European Union and a range of its Member States and the effect that these regulations have had on the development of the PMD market and the safety of those vehicles that have been permitted to use the public road network. These analyses have been combined with an extensive stakeholder engagement process and a review of existing standards and regulations from the EU and elsewhere to attempt to devise a regulatory scheme for both the technical and road circulation requirements for PMDs. The intention being to create a scheme of regulations that supports the development of the PMD market, which is both compatible with existing regulations for other vehicle types and is sufficiently flexible to ensure that it does not excessively restrict innovation in this fast developing market.

3. ASSESSMENT OF REGULATORY OPTIONS

There are four key issues to be addressed in the development of new or amended technical regulations for PMDs:

- The manner in which PMDs are separated from other categories of vehicle
- The criteria applied to sub-divide PMDs into sub-categories if it is necessary to do so
- The mechanisms by which the technical regulations are applied and enforced
- The specific requirements that should apply to each vehicle

In addition to these technical issues, consideration must also be given to the road circulation regulations that apply across the EU to the use of PMDs.

Given the historic norms and practices associated with road circulation regulations it is not possible to entirely decouple technical regulations from road circulation regulations. Put simply, the inclusion of a vehicle into an existing vehicle category for the most part automatically ensures that it will be treated for road circulation purposes like the other vehicles in the same category. Thus, to bring all PMDs within the scope of Regulation (EU) No 168/2013 would by default have a significant impact on the road circulation restrictions placed upon their use which would largely bring them into line with mopeds and motorcycles. Conversely to exclude PMDs from the scope of Regulation (EU) No 168/2013 would leave them outside of the current structure and thus entirely reliant on national derogations for their permission to be used on the road. When EPACs were first brought onto the market they were able to take advantage of their very close family links to pedal cycles and thus inherit the regulations that applied to them with very few additional technical restrictions. However, other types of PMD lack this link to similar historic types and are thus liable to be treated as entirely novel by national regulators. Indeed this has been evident from the diversity of approaches taken by different Member States to road circulation regulations for self-balancing personal transporters and e-scooters.

3.1. Options for regulations

In this section we present a series of potential regulatory options that could be considered in order to augment the scope of Regulation (EU) No 168/2013 to address the need for harmonised regulations for existing and emerging forms of PMD. In each case it is assumed that any amended regulation would not apply retrospectively to vehicles that are already in circulation. These options are not intended to be mutually exclusive, so for example option 2, 4 and 5 could all be enacted together.

3.1.1. Option 1: Inclusion of all PMDs within the scope of Regulation (EU) No 168/2013

In this first option all PMDs would be brought within the scope of Regulation (EU) No 168/2013. This would require the removal from Paragraph 2 of Article 2 of clauses a, h, i and j, thus bringing vehicles with a maximum design speed of 6km/h (a), pedal cycles with electric motor assistance up to 250W and 25km/h (h), self-balancing vehicles (i) and vehicles without at least one seating position (j) within the scope of the regulation. These vehicles would thus be subject to mandatory type-approval and the harmonised rules that apply to other L-category vehicles. Where appropriate these vehicles would be integrated into existing sub-categories, e.g. EPACs would be added to the scope of L1e-A. Where this was not appropriate, due to significant technical differences between a particular group of vehicles and all existing sub-categories, then new sub-categories within Regulation (EU) 168/2013 would be created.

3.1.2. Option 2: Removal from the scope of Regulation (EU) No 168/2013 of all PMDs with a maximum speed less than 25km/h

In this option all PMDs with a maximum speed less than 25km/h would be removed from the scope of Regulation (EU) No 168/2013. Clauses a, h, i and j of Paragraph 2 of Article 2 would be deleted, thus bringing many types of PMD, including standing e-scooters, hover boards and e-unicycles within the scope of the regulation. A further clause would be added to augment this change of scope in order to limit the regulation to vehicles with maximum motor driven speeds above 25km/h. Thus only PMDs with a maximum speed greater than 25km/h would be within the scope of the regulation, meaning that, for example, a standing e-scooter with a top speed of 20km/h would be outside the scope of the regulation but one with a top speed of 30km/h would be within the scope. The removal of clause j would in theory permit such a vehicle to be type approved within the L-category. This option would effectively remove the need for the L1e-A sub-category since all vehicles in that category would fall outside the scope of the regulation.

3.1.3. Option 3: Removal from the scope of Regulation (EU) No 168/2013 of all PMDs with a maximum speed less than 30km/h

In this option all PMDs with a maximum speed less than 30km/h would be removed from the scope of Regulation (EU) No 168/2013. Clauses a, h, i and j of Paragraph 2 of Article 2 would be deleted, thus bringing many types of PMD, including standing e-scooters, hover boards and e-unicycles within the scope of the regulation. A further clause would be added to augment this change of scope in order to limit the regulation to vehicles with maximum motor driven speeds above 30km/h. This option would also remove the need for the L1e-A sub-category and would slightly modify the scope of the L1e-B sub-category. In theory this option could require the creation of new sub-categories within Regulation (EU) No 168/2013 to accommodate novel designs of vehicle e.g. high-speed self-balancing vehicles, however it is not envisaged that such vehicles would be produced in the short to medium term. Here the removal of clauses i and j is intended to provide scope for development of new vehicle types at some point in the future.

3.1.4. Option 4: Removal from the scope of Regulation (EU) No 168/2013 of all PMDs with a maximum motor power less than 1,000W

In this option all PMDs with a maximum motor power less than 1,000W would be removed from the scope of Regulation (EU) No 168/2013. Clauses i and j of Paragraph 2 of Article 2 would be deleted, thus bringing many types of PMD, including standing e-scooters, hover boards and e-unicycles within the scope of the regulation. A further clause would be added to augment this change of scope in order to limit the regulation to vehicles with maximum motor power greater than 1,000W. This option would also effectively remove the need for the L1e-A sub-category.

3.1.5. Option 5: An EU harmonised system for the regulation of PMDs outside the scope of Regulation (EU) No 168/2013

In this option PMDs that fall outside of the scope of Regulation (EU) No 168/2013 would be subject to an EU harmonised approval process which would be tailored to the specific needs of PMDs. This system would harmonise standards for each PMD category across the EU. These categories would be defined using parameters that relate to the level of risk posed by the vehicle rather than its physical configuration. This system would be defined in a new regulation, separate from both Regulation (EU) No 168/2013 and the Machinery Directive. This new regulation would incorporate content intended to assure and promote road safety and the environmental sustainability of road transport. This regulation would be harmonised across all Member States to ensure a uniform approach to the granting of road circulation rights to all suitably approved types.

3.2. Factors to consider in amending regulations

3.2.1. The suitability of the Machinery Directive as a mechanism for the approval of road vehicles

Currently designs that fall outside the scope of Regulation (EU) No 168/2013 are treated as 'machines' and certified by their manufacturer or importer against a relevant standard under the provisions of the Machinery Directive. However, the Machinery Directive was never intended to be a mechanism for the approval of road vehicles and lacks content relevant to the assurance and promotion of road safety. The certification of a machine under the Machinery Directive does not automatically carry any rights that allow a machine to be used on the road. These rights are granted via national legislation in each Member State who may or may not permit certain types of machine, e.g. e-scooters, to be used on the road.

3.2.2. The inclusion of EPACs within the scope of Regulation (EU) No 168/2013

Option 1 would represent a significant increase in the scope of the regulation and would bring into scope a number of existing vehicle types that are currently on the market. The most significant of these, in terms of its effect on an existing and established industry, would be the inclusion of EPACs in the L category. We have seen no compelling evidence from either our review of literature and collision data or our engagement with stakeholders to suggest that the inclusion of EPACs within the scope of Regulation (EU) No 168/2013 would have a positive effect on the safety of these vehicles. On the contrary the evidence we have seen indicates that for the most part the current regulatory regime for EPACs is operating effectively in terms of its effect on safety and it appears to be having a positive effect on the market development of this group of vehicles. We did receive some evidence from stakeholders that indicated that tampering with EPACs in order to improve their performance is relatively common. One major manufacturer in the industry estimated that around 20% of EPACs were being modified to increase their maximum speed. However, we found no evidence to suggest either that tampering was associated with an increased safety risk in these vehicles, or that type-approval would be an effective mechanism to prevent it. We did receive submissions from stakeholders that suggested that the manufacturers' warranty and subsidised cycle leasing schemes both had a positive effect in reducing the prevalence of tampering, since the forfeiture of either of these facilities had a significant economic penalty associated with them which is more severe, but importantly, more likely to lead to detection, than any potential legal consequence of being caught with a tampered vehicle.

Regulation (EU) No 168/2013 includes the L1e-A sub-category for powered cycles up to 1,000W motor power and 25km/h maximum speed. This sub-category has failed to attract manufacturers and consumers who have opted instead for the lower powered but equally fast EPAC group of vehicles. While it is difficult to accurately predict the behaviour of the market in response to EPACs coming within the scope of Regulation (EU) No 168/2013 it seems likely that a significant proportion of current and future EPAC users would opt to use conventional pedal cycles or other modes instead of EPACs if the regulation were to change. EPACs initially gained popularity with older riders and it is likely that this group would revert to less active modes.

Pedal cycles like EPACs are uniquely disadvantaged by the type-approval process, which treats each variant of a vehicle as a separate type. This means that pedal cycles, whose frames are made in a variety of sizes to suit the physical dimensions of the rider, must undergo a separate type approval for each frame size.

3.2.3. The inclusion of self-balancing vehicles within the scope of Regulation (EU) No 168/2013

Options 1-4 would bring self-balancing vehicles above certain performance criteria within the scope of Regulation (EU) No 168/2013. In principle there is no fundamental barrier to the inclusion of these vehicles within the scope of the regulation. Consideration would have to be given to the inclusion of single wheeled vehicles, which are currently excluded by the wording of the regulation, which lists two and three wheeled vehicles and quadricycles but not single wheeled vehicles. However, much greater consideration would be needed for the appropriate technical regulations that would need to be applied to self-balancing vehicles since this type of vehicle is significantly different from all existing vehicles within the scope of the regulation in its complete dependence on an electronic control system to maintain balance and provide drive, steering and braking functions. The acceptance criteria for such a system would require significant research and development in order to ensure that these vehicles reached a level of safety compatible with use on the open road. Given their need for high motor powers in order to maintain stability, Option 4 would not have a significant exclusory effect on self-balancing vehicles, meaning that many of the designs currently available would fall within the scope of the regulations, however Options 2 and 3 would exclude many self-balancing vehicles from the scope of the regulation.

3.2.4. The inclusion of vehicles without seating positions within the scope of Regulation (EU) No 168/2013

Options 1-4 would bring vehicles without a seating position within the scope of Regulation (EU) No 168/2013. Like self-balancing vehicles there is no reason in principle why this type of vehicle could not be brought with the scope of the regulation. Some amendments would be needed to technical regulations to permit a vehicle without a seat to be approved. Consideration would also need to be given to the unintended consequences that might arise from the removal of Clause j of Paragraph 2 of Article 2 of the regulation, in particular the possibility that high performance vehicles e.g. those in sub-category L3e-A3 could now be type-approved without a seating position.

In practical terms however, options 2, 3 and 4 would exclude most types of standing e-scooter, e-skateboard etc. from the scope of the regulation due to their maximum speeds or motor power.

3.2.5. Opportunities arising from technological developments

During our investigation we came across two themes that may be inter-linked with potential benefits to users, manufacturers and regulators. The e-scooter rental schemes that are growing in popularity across many European cities rely heavily on GPS tracking and geo-fencing. Speed is a key parameter in ensuring the safety of PMDs and tampering in order to illegally increase the speed of PMDs is a prevalent issue. By incorporating GPS tracking and geo-fencing into all PMDs there is the possibility to create location and even time specific speed limits that can be easily monitored for compliance. Clearly there are issues of great sensitivity around the automated monitoring of the movements of identifiable individuals but an opportunity exists to create a category of vehicles in which intelligent speed limiting is built in from its inception with the possibility to demonstrate the utility of such technology for other categories of vehicle. As an example of what this might allow, cargo bicycles that rely on door-to-door access for their business model could be permitted to enter pedestrianised town centres, but automatically limited to 6km/h in the pedestrianised area, reverting to 25 or 30km/h when they leave. Alternatively time based geo-fencing might permit local authorities to establish delivery windows during which cargo bikes are permitted to enter the restricted area.

Built in connectivity also offers potential solutions to the problems of vehicle theft and misuse. Stolen PMDs could easily be remotely disabled and located while electronic 'number plates' could be used to identify PMDs used inappropriately or in the commission of a crime. We propose therefore that consideration be given to the way in which GPS tracking, geo-fencing and connectivity could be incorporated into new regulations for PMDs.

3.3. Assessment of options

3.3.1. Assessment of option 1 (type approval for all PMDs)

Option 1 would bring a variety of vehicles that are not well suited to type-approval into the scope of Regulation (EU) No 168/2013. In particular the physical size and technical characteristics of many PMDs is very different to vehicles that are currently type approved under Regulation (EU) No 168/2013. This would require the development of new technical regulations and the test methods and equipment required to undertake the tests. EPACs and other bicycle derived vehicles also suffer from the handicap that different frame sizes of the same design are treated as different types for the purposes of type approval, multiplying the cost and difficulty associated with bringing a new design to market. Option 1 would very likely have a strongly negative effect on the development of the PMD market and would significantly reduce sales of EPACs. This option would be very likely to meet strong resistance from industry and user groups.

3.3.2. Assessment of option 2 (remove vehicles <25km/h from scope)

The 25km/h cut off has been chosen to align with the current limit for both EPACs and L1e-A. The 25km/h limit has developed a significant historical basis and is well accepted by users, regulators and industry, but does not have a strong basis in science. Option 2 would create a clear delineation between vehicles that fall outside the scope of Regulation (EU) No 168/2013 and vehicles that fall within it. This option has the advantage that it is entirely technology agnostic, permitting the development of new designs without the restrictions of type approval. This simple cut-off also makes the regulation easy to understand and thus enforce. However, simply excluding vehicles from the scope of the regulation does not automatically imply that they can be used without restriction. Thus, by itself, Option 2 is not a solution to the issue of how the approval of PMDs can be harmonised across the EU.

3.3.3. Assessment of option 3 (remove vehicles <30km/h from scope)

Option 3 shares most of the advantages and disadvantages of option 2 but importantly would bring the speed limit for PMDs in line with the speed limits now being imposed in many urban areas. In doing so it would permit PMDs to more easily keep up with other traffic and avoid the necessity for them to be overtaken by other vehicles, thus reducing conflict and collisions caused by poor overtaking. However, the higher top speed of PMDs would have implications for the design of the vehicles and would thus require more robust technical standards and would also have the potential to make collisions more severe. There would need to be a carefully balanced scientific assessment of the relative benefits of reducing overtaking incidents while increasing the speed at which collisions occur before such regulatory change was introduced. Adopting a 30km/h limit would also bring EU regulations for EPACs into closer alignment with those in the USA (20mph) with associated benefits for commonality of production across both markets.

3.3.4. Assessment of option 4 (remove vehicles <1,000W from scope)

Option 4 is agnostic to maximum speed and would likely need to be combined with options 2 or 3 in order to create a coherent regulatory scheme. Like options 2 and 3, the removal of a group of vehicles from the scope of Regulation (EU) No 168/2013 does not automatically grant them the right to be used on the road and consequently this option would also need to be accompanied by measures to harmonise arrangements for approval. However, the key feature of this option is that in raising the power limit at which inclusion in the L-category is mandatory, it would facilitate the development of new designs of PMD that are not reliant on human power to achieve acceptable acceleration and top speed. One important note of caution is required however, in that raising the power limit would make tampering a more serious problem than it is currently, since vehicles with a 250W motor lack the power to go a great deal faster than 25km/h, whereas those with a 1,000W motor would be capable of rather higher speeds if they were to be tampered with.

3.3.5. Assessment of option 5 (create a dedicated PMD approval system)

Option 5 represents the greatest change in terms of the regulatory effort required to bring it into force but also has the greatest potential to create a step change in the way the regulation of PMDs is done across the EU. The main purpose of option 5 is to create a system that harmonises the approval process for PMDs across the EU and, unlike the Machinery Directive, seeks to ensure that the approach taken to the types of vehicles that are permitted to be used on the road is common to all Member States. Option 5 deliberately keeps PMDs outside of the scope of Regulation (EU) No 168/2013 and thus seeks to ensure that PMDs are not automatically treated as L-category vehicles for road circulation purposes. This however may have significant political implications in that it requires a relatively significant change to the traffic codes of each Member State. In order to minimise the requirement for the drafting of new national legislation the regulations for the use of PMDs should be closely aligned to those already in force for bicycles and by extension EPACs. Thus, we would recommend for this option that age limits, permitted routes, permitted behaviours etc. are copied from existing national bicycle regulations to the greatest extent possible. This would require reasonably close alignment between the performance of PMDs and pedal cycles to ensure that road circulation restrictions were appropriate and proportionate.

From a technical perspective the intention of option 5 would be to create a system for technical approval that is proportionate to the potential safety, societal and environmental benefits achievable through the regulation of small, relatively slow and relatively low powered vehicles. Careful consideration would need to be given to the way in which regulations were enforced and approvals issued. The vision here would be to produce a system that was sufficiently flexible in its requirements to ensure that the unique needs of the PMD industry were catered for, e.g. allowing a single approval to be issued for an EPAC model manufactured in a range of different frame sizes, while at the same time ensuring technical safety standards were maintained to an adequate level. This will require careful consideration to be given to the way in which technical requirements are specified e.g. requiring the frame size most susceptible to fatigue cracking or buckling to be tested. The intention would be that the system would to a significant degree mimic the self-certification requirements used in the Machinery Directive, but with specific requirements for external technical oversight and testing where appropriate. This oversight could be provided by appropriately qualified independent testing and validation organisations and would not necessarily need to be delivered by the same 'technical services' that are responsible for type-approval. This would minimise the delays caused by access to the existing technical services and would also permit specialist suppliers of testing and validation services to join the market.

In implementing this system considerable thought would need to be given to the organisational cultures present within the PMD industry and the manner in which manufacturers, importers and distributors can be best supported to ensure that the quality and conformity of their products do not cause undue safety or environmental issues. In particular the short product life-cycle and diverse and extended component supply chain that characterises many PMD types must be taken into account when devising new approval mechanisms. For the most part the PMD industry is not prepared for the same level of product conformity that would be expected from the automotive industry. Careful consideration needs to be given to the question of whether automotive levels of conformity are necessary to ensure the safety and environmental sustainability of PMDs. Clearly it cannot be acceptable, as one stakeholder shared with us, for an approval to be granted against a highly sensitive requirement like electromagnetic compatibility, but for the product to be sold with a different design of circuit board in every vehicle. However, it seems unnecessarily draconian to expect the same level of conformity in less sensitive systems.

4. Important Findings and Recommendations

4.1. Road circulation regulations

In section 9 we report the outcomes of our stakeholder engagement exercise in which, amongst other activities, we sought the opinion of stakeholders on the user restrictions, user behaviours and traffic rules that should be applied to PMDs. On the question of user restrictions there was very little agreement amongst stakeholders on whether regulations around age restrictions, licensing and insurance were appropriate or would be effective in ensuring the safety of PMDs. Mandatory licensing and insurance were seen as being highly impractical, as was the requirement for basic training. Stakeholders were however agreed that road circulation regulations for PMDs should be harmonised across the EU and that those regulations should take account of the risk associated with the performance of the vehicle, i.e. faster or heavier vehicles should be subject to stricter user restrictions.

On the question of user behaviour stakeholders were in much greater agreement, broadly agreeing that user behaviour should match that of pedal cyclists. An important factor in the success of EPACs has been the ease with which they were able to be integrated into the scheme of road circulation regulations that was already in existence for pedal cycles. Adopting these existing regulations meant that users and law enforcement authorities already had a good understanding of what was and was not acceptable behaviour and these behaviours had been codified into national and local regulations and traffic codes over a long period of time.

Stakeholders agreed that restrictions should be placed on the use of PMDs while intoxicated and the prohibition of using mobile phones while riding. However, there was greater disagreement on the mandating of protective clothing for PMD users, although there was broad support for the encouragement of helmet use and for the alignment of helmet regulations for PMDs with those for pedal cycles.

On the question of traffic rules there was support for the development of an EU harmonised approach. Stakeholders supported the idea that PMD users should follow national 'Highway Codes', obey specific speed limits for cycle paths, footways and roads and should be appropriately lit.

With these findings in mind, and drawing on the example of the way in which EPACs have been incorporated into widespread public use, we recommend that road circulation regulations for PMDs be aligned to those applied to pedal cycles as closely as is practical. This recommendation is conditional on the imposition of technical regulations that are designed to ensure that the risks associated with the design of PMDs, in particular their maximum speed, is compatible with regulations applied to pedal cycles.

This recommendation is based on the available evidence (Section 7) which suggests at present that there is no significant difference in the levels of risk associated with using a PMD and a pedal cycle. However, given the novelty and relative rarity of many types of PMD and the current lack of a harmonised approach to collision recording and reporting it is important to keep the safety of PMDs under review to ensure that developing safety trends are identified early and dealt with effectively.

4.2. Speed and motor power limits for PMDs

Most forms of PMD that are not derived from pedal cycles have maximum speeds that do not exceed 25km/h. This suggests that there is no fundamental incompatibility between new types of PMD e.g. e-scooters, and existing pedal cycle regulations which have been successfully applied to EPACs. However, most PMDs that are not derived from pedal cycles have electric motors that exceed 250W. These PMDs require more powerful motors because, unlike EPACs, they are relying entirely on the motor to propel the vehicle. While humans are not particularly powerful, reaching a peak of perhaps 150W unless highly athletically trained, they are able to produce a significant amount of torque which enables them to provide a high degree of assistance to an EPAC when climbing a steep gradient. Without that human assistance for starting and climbing, other types of PMD require a motor with more torque. Thus, the extra power available for PMDs that aren't derived from bicycles should not be thought of as providing them with a performance advantage, but rather compensating for their lack of human support. We would therefore recommend a blanket power limit for all PMDs outside of the scope of Regulation (EU) No 168/2013 of 1,000W (Option 4), which would provide sufficient power for most designs and configurations of vehicle. An exception may be necessary for self-balancing vehicles as they rely on motor power to remain upright and may therefore be rendered unsafe by an artificially low limit. In all cases the maximum speed of the vehicle should be considered more important than its motor power. Here we would suggest that the limit for PMDs outside the scope of Regulation (EU) 168/2013 be set to 30km/h (Option 3) to bring the speed of these vehicles in line with the speed limits now being used in many urban areas. However, careful monitoring must be undertaken to ensure that this higher limit does not lead to a significant increase in casualties.

4.3. Additional regulation of EPACs

We found evidence from research (Section 7.1) that showed that, when the distance travelled was taken into account, there was no difference in the risk of injury between using an EPAC and a conventional bicycle. We therefore recommend that no new restrictions be placed on the construction and use of EPACs.

4.4. Type-approval issues for PMDs

Evidence from stakeholders with experience of having been through the type approval process for powered cycles in L1e-A and cycles designed to pedal in L1e-B indicates that the cost of type approval for each type was between €20,000 and €40,000. It should be noted that for pedal cycle derived vehicles different frame sizes of the same model and men's and ladies' versions of the same model are treated as separate types for type approval purposes. Thus, the overall cost of getting one model of bicycle approved may be some multiple of that figure. However, the costs of type approval do not add significantly to the overall purchase price to the consumer – one manufacturer estimated that type approval added only €8 per vehicle sold. More important than the economic cost of the process was the incompatibility of the business model of many PMD manufacturers and importers who have a short design cycle, often releasing new models every year and a diversified supply chain that has been developed to ensure resilience and redundancy so that component availability never stops production. This approach is fundamentally at odds with the type-approval system which requires design-freeze at the point of assessment and robust conformity of production throughout the product's lifecycle. Clearly some middle ground needs to be found that ensures the safety and environmental sustainability of PMDs while acknowledging the differences in business approach between the PMD and automotive industries. An approach that is proportional to the level of risk resulting from potential technical failures should be devised.

4.5. Changes to L1e-A

The L1e-A sub-category has failed to attract manufacturers and consumers as it is insufficiently differentiated from the performance specification for EPACs but has significantly greater barriers for both manufacturers and users. The L1e-A sub-category could be repurposed to encompass the existing cycles designed to pedal in L1e-B. The existing 1,000W power limit could be retained as this exceeds the motor power of all cycles designed to pedal in L1e-B currently on the market while the maximum assistance factor limit could be relaxed or removed altogether since the power limit for the sub-category would provide sufficient differentiation from L1e-B. The speed limit for the sub-category could be raised to 45km/h. The revision of this sub-category would provide for a convenient mechanism by which cycles designed to pedal could be regulated separately from mopeds. This would allow special consideration to be given to the standards and tests that need to be applied to these vehicles without inadvertently interfering with the arrangements in place for mopeds. Moving cycles designed to pedal into L1e-A would also permit manufacturers to design three and four wheeled cycles designed to pedal, which are currently not permitted under L1e-B, thus creating a sub-category that would be highly suitable for pedal assisted cargo tricycles and quadricycles. Consideration should also be given to whether or not it is necessary to limit the maximum number of wheels in this sub-category, since this may hamper innovation.

4.6. Approval of cargo bicycles, tricycles, quadricycles and others

There are potentially significant safety and air quality benefits to be derived from replacing diesel vans with electrically assisted cargo bikes for urban distribution tasks e.g. parcel delivery. One of the primary concerns of the electrically assisted cargo bike industry is that they may lose their rights of access to urban areas as a result of restrictions being placed on L-category vehicles to improve safety and air-quality. The current 250W limit applied to EPACs is too low for the heavier pedal assisted cargo bikes that are now growing in popularity. Manufacturers in this sector are more positively disposed towards type-approval than their counterparts in the consumer EPAC sector but worry that inclusion in the L-category risks their products being banned from urban areas. Given the nature of these vehicles, which are much heavier and physically much larger than other PMDs, although not any faster, a heightened degree of technical oversight is appropriate. Manufacturers in this sector tend to have a smaller range of products and a longer product life cycle, making them less sensitive to the type-approval issues identified above. There are two options to ensure that the cargo bike industry is not prematurely curtailed by a ban intended to target petrol engined powered two-wheelers, the first is to exclude them from the scope of Regulation (EU) No 168/2013 and instead regulate them via Option 5 as described in Section 3. Under this regime the technical standards applied could be more strict than those applied to other PMDs. The second option would be to include them within the scope of Regulation (EU) No 168/2013 but to provide guidance to Member States and local authorities to ensure that any ban on the use of powered two-wheelers in urban areas is worded in such a way that they do not inadvertently prohibit electrically assisted cargo bikes.

4.7. Collison reporting and recording for PMDs

Currently there is significant diversity in the way national authorities record and report collisions involving PMDs. Most Member States do not report collisions involving EPACs, cycles designed to pedal in L1e-B or other types of PMD separately. Collisions involving these types are either included within the statistics for conventional bicycles or mopeds, thus making the analysis of the safety of these types impossible. Member States should be encouraged to adopt a harmonised methodology for recording and reporting collisions involving PMDs.

4.8. Tampering

Tampering in order to increase the maximum speed of EPACs in particular is prevalent, with one large manufacturer suggesting that around 20% of EPACs were being tampered with, one retailer suggested that this figure might be as high as 85% in some Member States. Some police forces are now taking enforcement action against users of vehicles that have been tampered with. This action is being supported by some manufacturers who are helping to deliver training to officers in order to help them identify vehicles that have been tampered with. Manufacturers should be encouraged to work with enforcement authorities to support the detection of vehicles that have been tampered with. Manufacturers should also be encouraged to devise technical solutions to prevent tampering or to find other ways to reduce the prevalence of tampering e.g. by voiding warranties on tampered vehicles. Manufacturers in the PMD industry do not have the same relationship with their dealer and service network that automotive manufacturers do. This makes it harder for them to exercise control over their vehicles once they have been manufactured. Currently tampering is not illegal, even though using the tampered vehicle may be prohibited by national regulations. Consideration should be given to the creation of regulations to prevent tampering by dealers and maintenance organisations, although this would likely have to be done at a national rather than EU level. Consideration should also be given to the reasons why users want their vehicles to be tampered with. With a maximum speed of 25km/h, EPACs are slower than other vehicles on the road, even in areas where a 30km/h speed limit has been adopted. It may be that by raising the limit for EPACs and other PMDs to 30km/h the primary driver for tampering may be removed. Though here care is required to ensure that the risk profile of these vehicles is not significantly raised by this apparently small change in regulation.

4.9. Vehicles intended primarily for off-road use

Regulation (EU) No 168/2013 excludes from its scope vehicles intended primarily for off-road use. There is however concern amongst stakeholders that this exclusion is being used as a loop-hole to permit high-powered vehicles to be placed on the market without proper regulation. In particular there is concern in the mountain bike industry that the use of vehicles, that are in reality electric motorcycles with pedals, on mountain bike trails, will lead to enforcement action by land owners and the loss of these trails for legitimate mountain bike riders. There is also concern that these vehicles are difficult to differentiate from EPACs and are liable, wittingly or otherwise, to be used illegally on the road where they are likely to be difficult to distinguish from legally ridden EPACs. The Commission should assess the risk of harm to users of off-road tracks and trails, and the risk that legitimate mountain bike users may lose access to these spaces and consider whether there are any mechanisms open to them that would help to control the illegitimate use of vehicles intended primarily for off-road use and whether doing so would be proportionate and appropriate.

4.10. Vehicles intended solely for the use of those with a physical disability

Vehicles intended solely for the use of those with a physical disability are outside of the scope of this study. However, it was brought to our attention during our investigation that there are significant safety concerns around loss of control collisions involving this type of vehicle. We understand that one Member State is suffering in excess of forty fatalities per year in incidents involving these vehicles. However, these problems were only highlighted by two stakeholders in our study. We recommend therefore that further work be undertaken to establish whether this problem is unique to that Member State and whether action is needed on the part of the Commission to improve the safety of these vehicles.

5. Detailed description of personal mobility devices available in the European Union

There is a diverse and rapidly changing range of PMDs available for sale in the EU and hence it would not be possible to create an entirely accurate and up to date inventory of all PMDs available on the market. Instead we sought to document a sample of vehicles which seeks to illustrate the diversity of designs available and capture the key design features observed in these vehicles.

Figure 7 illustrates the working taxonomy that was applied in the collation of our inventory. The intention of this first-pass taxonomy was only to permit devices to be readily grouped according to their most prominent features and thus ensure that the coverage of our search included a sufficient diversity of designs. This taxonomy was further refined using the descriptions in Table 1. While not arbitrary, this working taxonomy was not intended to represent any potential future categorisation of types of PMD for regulatory purposes.

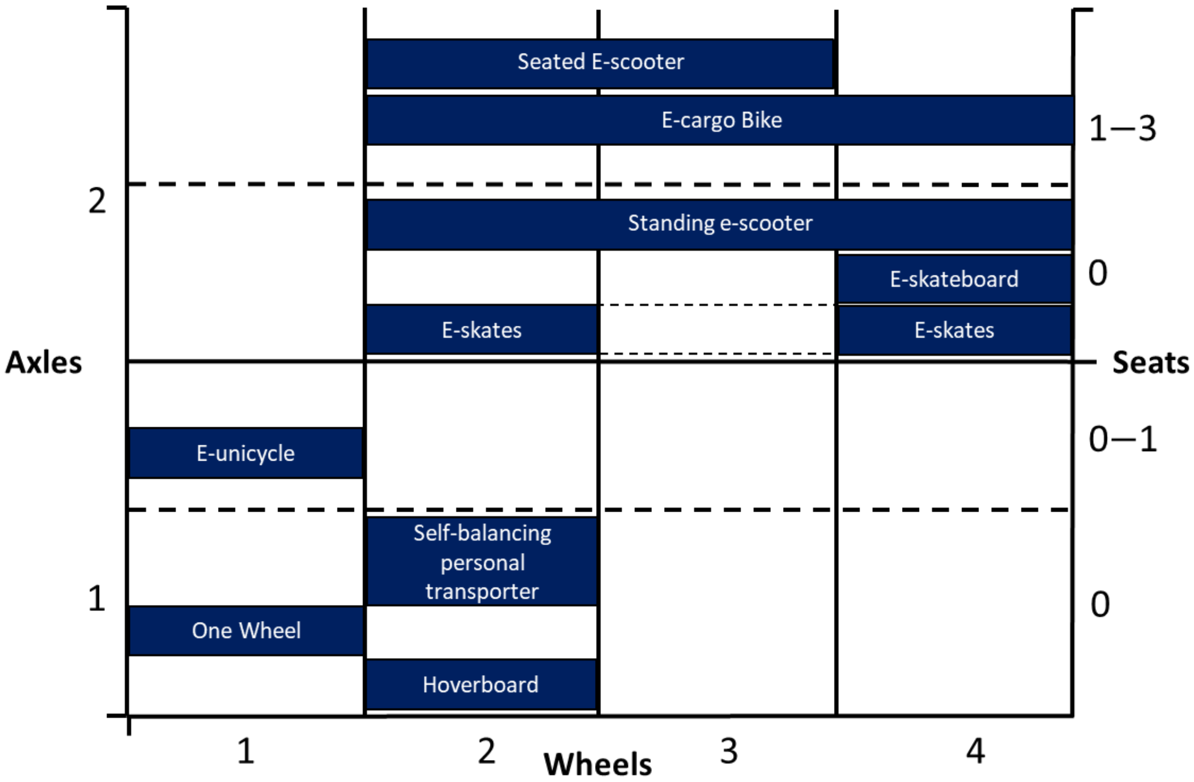


Figure 7: PMDs classified by number of axles, wheels and seats.

Table 1: Description of the characteristics of PMDs reviewed and the manner in which they were grouped

Group name	Description of each group
Seated E-Scooter	More than one wheel, where there are two wheels they are directly behind one another. Could have more than two wheels. Has two axles. Has at least one seat. Usually has handlebars.
Standing E-Scooter	Feet stand between the wheels. More than one wheel, where there are two wheels they are directly behind one another. Could have more than two wheels. Has two axles. Does not have a seat. Usually has handlebars.
EPAC	A pedal bicycle assisted by an electric motor. Has pedals. Has at least one seat. Has at least two wheels. Has two axles. Max power 250W, max assistance speed 25km/h.
Speed Pedelec[12]	A pedal bicycle assisted by an electric motor. Has pedals. Has at least one seat. Has at least two wheels. Has two axles. Max power >250W or max assistance speed >25km/h
E-Cargo Bike	A pedal cycle assisted by an electric motor. Has a cargo/load section to carry goods. Has pedals. Has at least one seat. Has at least two wheels. Has two axles.
Self-balancing personal transporter	Rider stands with feet between the wheels. Has two wheels on one axle, has no seats. Usually has handlebars or a knee stick to steer the device.
Hoverboards	Rider stands with feet between the wheels. Has two wheels on one axle, has no seats. Has no handlebars.
Hovershoes/ E-skates	Rider stands with feet above the wheels. Has at least two wheels. Has at least one wheel on two separate devices/shoes. Has two axles. Has no seats. Has no handlebars.
One-Wheel	Has one wheel. Rider stands with feet fore and aft of the single wheel with body facing sideways. Has one axles, has no seats. Has no handlebars.
Unicycle	Has one wheel. Rider stands or sits with feet either side of the single wheel with body facing forward. Could have a seat. Has no handlebars.
E-Skateboards	Has four wheels on two axles, has no seats. Has no handlebars. Rider stands with body facing sideways on device. Rider's feet stand on top of the board (on top of the wheels).
Go-Karts	Usually a kit to attach to a hoverboard. Operated by either steering wheel or levers. Has three to four wheels on two axles (this is including the hoverboard). Has at least one seat.
Other Electric Vehicles	Does not fit into any of the other categories for various reasons.

5.1. Inventory

An inventory was collated from a series of internet searches for the various groups of PMD given in Table 1. The inventory aimed to capture any device that could be purchased in

[12] This group includes cycles designed to pedal in L1e-B, but we have also included machines that do not fully meet the requirements of Regulation (EU) No 168/2013 for this sub-category for various reasons e.g. they exceed the maximum assistance factor limit

the EU including retailers who would ship to the EU from outside. The inventory has been provided as a separate electronic appendix.

The aim in collating this inventory was to establish the breadth of the variety of devices that were available, rather than to collect an exhaustive list of every device available. We aimed to include the extremes in our non-exhaustive list but also the most common and best-selling. Some categories (e.g. self-balancing personal transporters, hovershoes and standing e-scooters) include an almost exhaustive list true of the time of inventory collation as there were few on the market however categories such as e-bikes could not be as exhaustive because there are so many on the market.

The following parameters were recorded for each device:

- Maximum continuous or rated power,
- Maximum device design speed and cut-off speed of auxiliary propulsion,
- Dimensions: width, length, height, seat height and ground clearance,
- Load platform dimensions and minimum volume that can be carried,
- Laden and unladen mass,
- Maximum rider mass,
- Type of propulsion and engine/battery capacity,
- Number of axles and wheels,
- Number of seating positions / occupants,
- Anti-tampering measures,
- Dimensions,
- Braking,
- Steer-ability,
- Stability,
- Lighting and conspicuity,
- Audible warning device,
- Electrical safety,
- Rearward visibility,
- Device structure integrity,
- Stands,

The number of PMDs assessed within each group is listed in Table 2.

Table 2: Number of devices in each category of the inventory

PMD Type	Count
Seated e-scooter	45
Standing e-scooter	71
E-Bike (including EPACs and speed pedelecs)	40
E-Cargo Bike	9
Self-balancing personal transporter	5
Hoverboard	34
Hover-shoes/ E-skates	13
E-Skateboard	25
E-Unicycle	30
One-wheel boards	3
Total	**275**

5.2. Maximum device design power

Table 3 shows the minimum, median and maximum power of each category of vehicle in the inventory.

Table 3: Average, minimum and maximum power of each device category

	Min. power (W)	Median power (W)	Max. power (W)
Seated e-scooter	100	450	3,200
Standing e-scooter	150	350	3,600
E-Bike/EPAC ≤25km/h and 250W	200	250	250
Speed Pedelec	250	750	4,000
E-Cargo Bike	250	250	500
Self-balancing personal transporter	700	1,200	1,600
Hoverboard	135	400	700
Hovershoes/ E-skates (per pair)	80	500	700
E-Skateboard	100	250	3,000
E-Unicycle	320	1,500	4,000
One-wheel board	750	750	750

Average maximum power of the devices captured in the inventory ranged from 250W to 4,000W.

The top maximum power for both e-scooter categories is due to models of e-scooter which are designed for off road use.

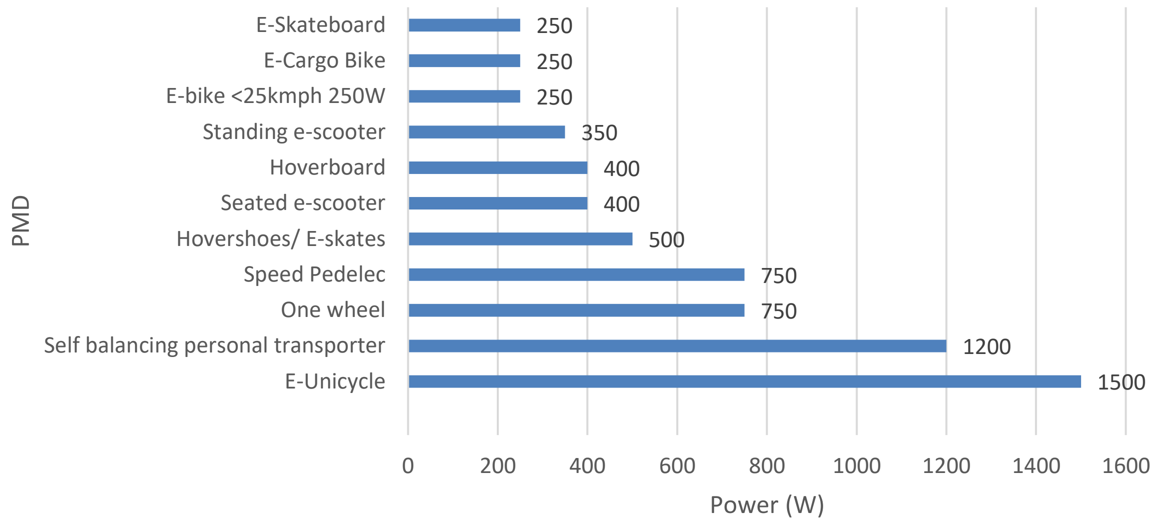


Figure 8: Median power of PMDs by group

Some of these devices, e.g. self-balancing vehicles, rely on having more torque, and consequently power, available to ensure stability, which is not necessarily reflected in higher speeds or greater accelerations in these vehicle types.

Figure 9 shows that some devices are equipped with high maximum powers despite the overall group having much lower median maximum powers. This implies that some devices in the group have unusually high power.

The highest maximum power for each group is mostly an outlier in each case which skews the average values (hence why we displayed the data using medians). Figure 9 provides an illustration of this point using seated e-scooters as an example. This is true for e-scooters seated and standing, e-bikes and e-skateboards.

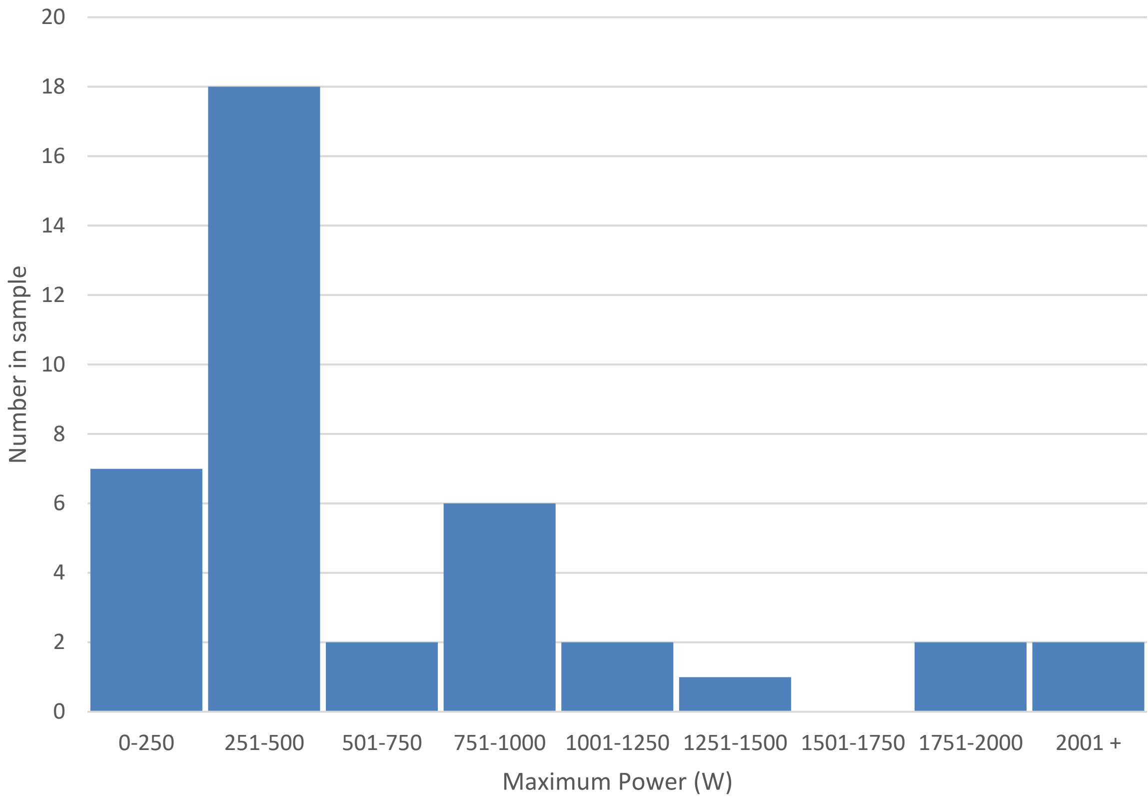


Figure 9: Numbers of seated e-scooters found arranged according to their advertised maximum motor power

Figure 9 illustrates the fact that seated e-scooters are available with a wide spectrum of maximum motor powers. This pattern was repeated in all of the groups surveyed other than EPACs which are restricted by regulation.

5.3. Maximum device design speed

Table 4: Advertised maximum speeds of each group

	Lowest max speed (km/h)	Median max speed (km/h)	Highest max speed (km/h)
Seated E-scooter	15	30	95
Standing E-scooter	13	25	100
E-Bike/EPAC ≤250W and 25km/h	25	25	25
Speed Pedelec	27	45	80
E-Cargo Bike	24	25	25
Self-balancing personal transporter	16	19	20
Hoverboard	10	12	16
Hovershoes/ E-skates	8	12	18
E-Skateboard	12	20	37
E-Unicycle	12	25	50
One-wheel	18	30	30

The median maximum speed of the devices captured in the inventory ranges from 12km/h for hovershoes and hoverboards to 45 km/h for speed pedelecs. The maximum speeds for the two e-scooter categories are due to the off-road style scooters that were found in the inventory. There was also a lack of information about the e-cargo bikes speed, only half of them provided a maximum speed.

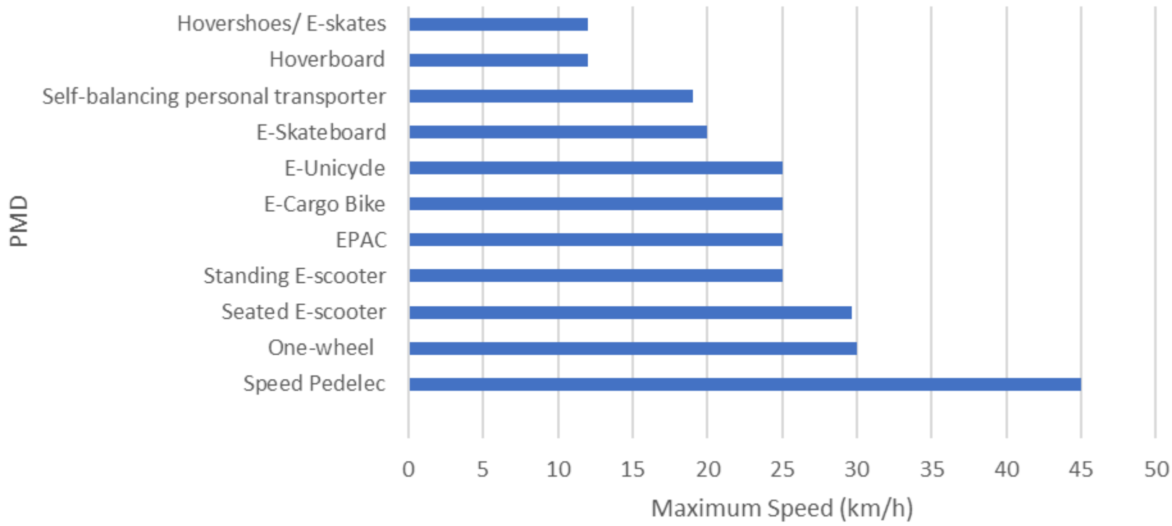


Figure 10: Median maximum speed of PMDs

Where they are legal (e.g. e-bikes and e-scooters) there is often a mandated speed limit of 20 or 25 km/h (12.5-15.5 mph). Similarly, speed limit can and should be dependent on area of operation e.g. footpath, road, cycle lanes. Some countries have speed limits for use on pedestrianised areas of 6-10km/h.

E-bikes have a maximum assistance speed rather than a maximum speed as they can also be manually pedalled meaning that the ultimate regulation of the top speed of these vehicles must be a matter for enforcement on the road rather than through technical regulations. That however does not preclude the possibility that the speed at which motor assistance stops should be a matter for regulation.

One regulatory issue is that not all of these devices have speedometers so that the rider can stick to the speed limit. The device should have a speedometer or a pre-set speed limiter. There is also the possibility, with the advent of accurate GPS positioning technology, that PMDs could be equipped with a system that limited their top speed according to the location where they were operated, thus allowing national or local authorities to set mandatory speed limits for certain infrastructure types e.g. cycle routes, or for certain locations e.g. town centres.

Braking distances increase with speed therefore technical regulations for braking performance need to match the allowable speed limits for each type.

5.4. Masses

Table 5: Average, minimum and maximum mass of each device category

	Min. mass (Kg)	Median mass (Kg)	Max. mass (Kg)
Seated e-scooter	11	27	99
Standing e-scooter	6	13	52
EPAC ≤250W and 25km/h	16	33	68
Speed Pedelec	23	34	113
E-Cargo Bike	26	49	125
Segway	13	14	16
Hoverboard	6	10	18
Hovershoes/ E-skates	6	6	13
E-Skateboard	4	5	11
E-Unicycle	4	13	47
One-wheel	9	18	12

The median mass of the devices captured in the inventory ranges from 5kg for a pair of hovershoes to 49kg for an e-cargo bike.

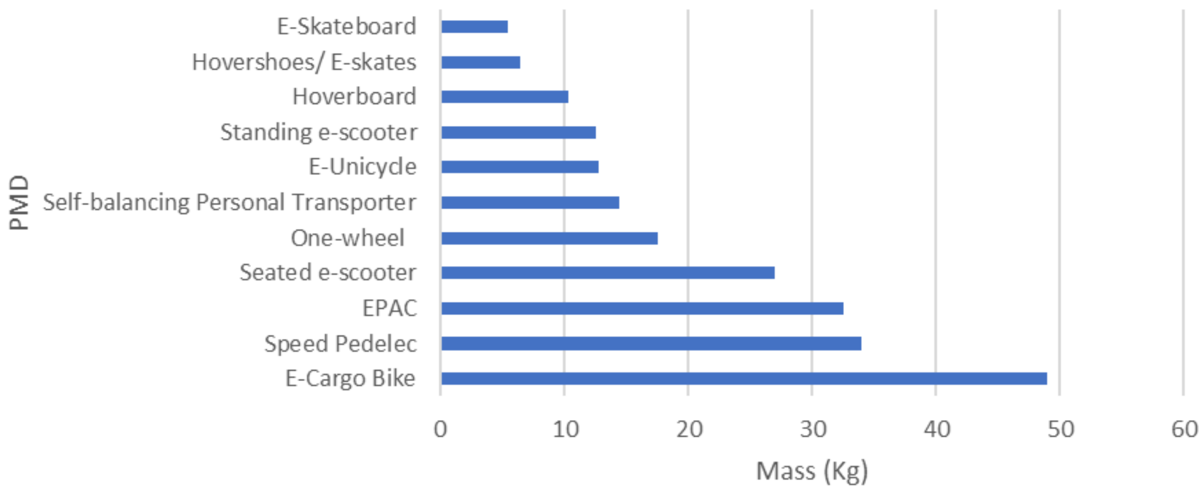


Figure 11: Median mass of PMDs

5.5. Anti-tampering measures

Anti-tampering measures are defined by article 19 and 20 in Regulation (EU) No 168/2013 as defeat devices and modifications to powertrain. No such devices were mentioned in conjunction with any of the device descriptions within the inventory.

This may be because the advertising and information supplied for these devices tended to be marketing the devices to exhibit the fun element rather than safety features.

There also seems to be no demand from the industry that devices would need to be fitted with anti-tampering devices because most of it is unregulated.

It's unlikely that a company would advertise ways in which control measures can be overridden, in the same way that the manufacturers of power tools don't show how you can take the guards off and make the machine to operate as normal.

However, there are many online videos of people showing how to tamper with your e-bike to make it go faster than 25km/h. Tampering does not need to be made impossible, as this would be a seemingly impossible task

5.6. Anti-theft and anti-vandalism

There could be anti-vandalism and damage protection for fleets of hire devices such as e-scooters and also many devices could come with anti-theft devices such as alarms and keys. Also, added security for personal devices could come from apps that register the specific device.

Three out of the 43 seated e-scooters in the inventory have anti-theft alarms/devices. Six out of 38 e-bikes had an alarm or locking system (smartlock, steering lock, self-locking motor). One cargo e-bike out of 9 had an alarm system. No other anti-tampering measures were noted for the rest of the devices as it was unknown, not available or not present.

5.7. Dimensions

The size of the device correlates well to their mass. The one outlier when correlating size to speed, power and mass is the e-unicycle. For its small size, the e-unicycle is very fast and very powerful.

The SAE (2019) classifies personal mobility devices as follows:

- Standard width (WD1) <0.9m
- Wide (WD2) 0.9 - 1.2m
- Extra wide (WD3) 1.2 - 1.5m

Many devices did not specify which figure, within this format X x Y x Z, corresponded to length, width or height and when specified was not consistent across all devices or manufacturers. Some devices did not state their dimensions.

From the information we have, it is not clear whether any of the devices identified in the inventory fall outside of these categories.

5.8. Braking

Below is a breakdown of the braking systems that each set of devices use. Table 6 shows the braking systems of e-scooters, Table 7 that of e-bikes, Table 8 devices with one wheel and Table 9 hover devices.

Table 6: **E-scooters' braking systems (total number of devices shown in column header in parentheses)**

E-scooters	Seated (43)	Standing (70)
Disc brakes	21	18
Drum brakes	5	8
Regenerative / electric brakes	2	21
Hand operated (rear or front)	7	2
Foot brake	0	18
Two or more *different* braking systems	4	28
Only one brake	12	9
Unknown	11	13

The way that brakes were described on the e-scooters varied greatly. For example:

- Different types of disc brakes (electric, hydraulic, not specified)
- Different types of electric/ regenerative (KERS, EBS, electric)
- Rear manual footbrake (foot brake, rear-fender brake, kick brake)
- Hand operated brakes were not further explained (assume to be calliper, disc or drum)

It is worth noting that many of the e-scooters used a dual braking system using just one type of brake.

Table 7: E-bikes' braking systems (total number of devices shown in column header in parentheses)

E-Bikes	EPACs (23)	L1e-B (13)[13]	E-cargo Bikes (9)
Disc brakes	13	10	8
Drum brakes	5	1	1
Regenerative / electric brakes	0	1	0
Piston	0	3	0
V-brakes	7	0	0
Two or more *different* braking systems	7	2	0
Unknown	3	1	1

Five e-bikes used a front disc and rear drum brake combination.

Table 8: One wheeled devices' braking systems (total number of devices shown in column header in parentheses)

One-wheeled devices	E-Unicycles (30)	One-Wheel's (3)
Regenerative / electric brakes	5	0
Plastic brake pad	1	0
No brakes	1	1
Unknown	23	2

Table 9: 'Hover devices' braking systems (total number of devices shown in column header in parentheses)

Other small devices	E-skateboards (24)	Hover shoes (13)	Hoverboards (34)	Self-balancing personal transporters (5)
Regenerative / electric brakes	6	13	34	5
None	0	0	0	0
Unknown	18	0	0	0

In a multi-wheel vehicle like an e-scooter, braking through a single wheel, rather than all wheels is less efficient and develops less decelerating force. Having a single brake also removes the added functional redundancy that comes from having a second system,

[13] The totals of these tables do not add up to the total number of devices e.g. if a device had disc brakes and drum brakes it would be counted in disc, drum and 'Two or more *different* braking systems'.

meaning that a single component failure e.g. a cable snapping, can leave the rider with no way to stop the vehicle.

Vehicles that use regenerative braking rely on their drive motors to also provide retardational force. In the case of self-balancing vehicles the braking, accelerating and balancing functions are all entrusted to the drive motors and their associated control circuitry. The reliability of those systems are thus crucial to the safety of the vehicle since any failure could prevent the rider from stopping the vehicle or cause it to overturn. Given the necessary complexity of such systems the procedures for their design, construction and verification must be rather more sophisticated than those applied to more traditional mechanical systems. The mechanical, electrical, electronic and software systems of the vehicle are all potential sources of failure, many of which may not be apparent on inspection. The use of control electronics means that the electromagnetic compatibility of the system must be considered to ensure that internal or external electromagnetic sources cannot impair the functioning of the braking system. The software algorithms must be carefully checked to ensure that braking will be applied in a predictable manner under all operating scenarios. Consideration must also be given to the effect of battery charge status on braking performance and safeguards implemented to ensure that the state of charge of the battery cannot adversely affect the braking performance of the vehicle.

Self-balancing vehicles do not lend themselves to the use of, potentially more reliable, mechanical service brakes, since applying the brakes causes the vehicle to pitch forward which the self-balancing mechanism would usually compensate for by attempting to accelerate to bring the wheels back under the rider's centre of gravity. It is conceivable that a system could be developed that allowed a self-balancing vehicle to use a mechanical braking system under the control of the electronic control system, but this would still have the intrinsic issue that a failure of the control system would either overturn the vehicle, or prevent it from stopping, or both. These issues with vehicles that use regenerative braking are not impossible to solve, but extra caution must be taken in the implementation and regulation of such systems.

5.9. Steer-ability or steering mechanism

The steering input used by the PMDs found in the survey fell into three groups:

- 'Handlebars' (used in Standing e-scooter, e-bike, e-cargo bike, seated e-scooters)
- 'Lean to steer' in which the rider leans their body to one side to command the direction change (used in self-balancing personal transporters, hoverboards, hover-shoes, e-skateboards, e-unicycle, one-wheel)
- 'Steering wheel or steering levers' (used in E-go-kart kits for hoverboards)

The mechanism by which direction change is accomplished also fell into three groups:

- 'Mechanical steering' in which one or more wheels are rotated about a (nearly) vertical axis
- 'Electrical torque control' in which the torque to the driven wheels on either side of the vehicle is increased or decreased in a differential manner in order to slightly speed up or slow down the wheel(s) on one side of the vehicle relative to the other
- 'Rider weight shift' in which the rider's weight is used to tip the vehicle slightly causing it to describe a curved path. In the case of E-skateboards that action is augmented by a mechanical system that also steers the wheels relative to the board.

Table 10: Steering classification

Mechanical Steering	Electrical Torque Control	Rider weight shift
Handlebars:	Hoverboard	E-skateboard
E-scooters	Hovershoes	E-unicycle
E-bikes (all kinds)	Self-balancing personal transporter	One-wheel
	E-go-karts	

Seated e-scooters mainly use handlebar steering however there are two exceptions (out of 43 devices) which use lean to steer instead. These two devices are hybrid e-scooter/ unicycles in the sense that they fit within e-scooter categorisation because they have two axles and wheels instead of one and it has a seat.

E-go-kart accessory kits for hoverboards use either a steering wheel (n=4) or levers (n=5) to control the steering.

Lean to steer devices take the user practice to operate. Therefore, the user is likely to get some minor injuries during this period, making them seem more dangerous. If this training period is done in a safe space this hazard to riders and pedestrians may be reduced. 'Lean to steer' is often combined with 'lean to accelerate and brake' which can add an additional complication to the process of learning to ride these devices. For vehicles that use electrical torque control, as you lean in one direction the device speeds up one wheel (the outside wheel) and slows the other down by decreasing power. Unicycles and one-wheels are steered directly by leaning, which causes a camber-steer effect like you get when you lean a bicycle over to steer it. E-skateboards are steered like an ordinary skateboard.

Handlebars are present on e-scooters and e-bikes and this provides an extra feeling of security as the user can hold on and accurately feel the steering they are performing. Handlebars may be more intuitive to learn to use than 'Lean to steer'.

Steering wheels and levers are traditional methods of steering for go-karts and have been translated into mechanisms which can steer a hoverboard which is attached to the go-kart conversion kit.

5.10. Stability

The stability of the device is generally associated with the number of wheels the device has, although the height of the centre of gravity and the arrangement of the wheels are also important.

- **Intrinsically stable** means that the vehicle is longitudinally, laterally and dynamically stable e.g. vehicles with four wheels in which the wheels are fixed close to the corners of the vehicle.

- **Dynamically unstable** means that the device is stable when stationary but may have stability issues in use. This applies particularly to vehicles that have a high centre of gravity, narrow wheel track and short wheelbase.

- **Longitudinally stable** means that the vehicle cannot fall over forwards or backwards when stationary but will fall sideways if unsupported e.g. a bicycle. These devices rely on gyroscopic forces produced by the rolling wheels and inputs from the rider to maintain balance. They therefore do not require active control systems to maintain stability.

- **Laterally stable** means that the device cannot fall over sideways when stationary but will fall forwards or backwards if unsupported when in motion e.g. hoverboard (it cannot fall sideways due to wheels positioned along one axle) although it is still possible for the user to fall laterally from the vehicle. These devices rely on torque from the drive motors to counteract their tendency to overbalance forwards or backwards. They therefore require active motor control to maintain stability.

- **Intrinsically unstable** means that the device could fall in any direction unless supported. These devices typically rely on the rider to maintain lateral balance and a combination of drive motor torque reaction and rider posture to maintain longitudinal balance. These devices therefore require active motor control to maintain balance.

Stability may affect the safety of PMDs, i.e. less stable vehicles are more likely to be involved in collisions resulting from the overturning of the vehicle. Where a vehicle relies on an active control system to maintain balance then the reliable functioning of that system is also important to the safety of the vehicle.

While some configurations of vehicle may be inherently more stable than others, the detailed design of the vehicle is likely to have a more significant effect on stability in use e.g. a four wheeled roller-skate may be statically more stable than a bicycle, but a properly designed bicycle will in practice be more stable than the roller-skate when in motion. Other factors are also likely to affect the stability of devices in use, in particular the effect of road surface imperfections and obstacles such as kerbs and tram tracks may be particularly dangerous to vehicles with smaller wheels and higher centres of gravity. Speed may also have a significant effect on stability, with some vehicles requiring a relatively high forward speed to maintain stability e.g. bicycles, which are unstable at very low speeds, while some become less stable at high speeds e.g. hoverboards, which rely on being able to accelerate to prevent overbalancing forwards, which is not possible at the devices maximum speed.

5.11. Lighting and conspicuity

The provision of lighting varied considerably both across different types of PMD, but also within each group of PMDs. Reasons for this may include maturity of the device type within the market, positioning in the market, the demographics of likely purchasers and their subsequent use cases once they have purchased, cost, and regulation and standards (or lack thereof) for PMDs in this area. Other factors include the design or basic shape of the PMD and lack of potential locations for appropriate lighting.

Even where lighting was provided, there were differences in key aspects between and within different PMDs, for example, colour, brightness, location and size. Some types of PMD are intrinsically more difficult to fit with effective lighting than others because of the configuration of the device, e.g. e-scooters typically lack any structure at the rear of the vehicle that is sufficiently high above the road to allow the fitment of an easily seen rear light. The diversity of PMDs, particularly in terms of shape and size, may mean that legislating for a standardised lighting provision across all device types could be challenging. The only PMD device type identified that had no lights across all the examples studied was skateboards.

The inconsistencies in lighting provision on EPACs is likely to stem from the fact that after market, simple to affix, lights are widely available for bikes, however a number of manufacturers at the higher end of the road e-bike market have taken the opportunity to integrate lights into the onboard power supply. Cycles designed to pedal in L1e-B are required to be fitted with front and rear lights.

ISO4210 specifies that bicycles ‘shall be equipped with reflectors at the front, rear, and side’, therefore EU market EPACs and L1e-A/Bs should come with standard fit front and rear reflectors, providing a level of illumination in certain scenarios, and requiring no power source. Adoption of reflectors by other PMD types was mixed, and the provision, or otherwise, of them was often not mentioned and only identified where possible through images accompanying specifications. Universal fitment of reflectors would provide a minimum level of conspicuity. As with other forms of lighting, benefits may vary considerably depending on how high on the PMD a reflector could be mounted. There may also be issues around reflectors providing riders with a false level of confidence that they are sufficiently visible, meaning other conspicuity options may not be adopted.

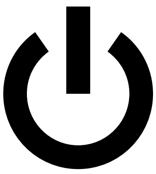
5.12. Audible warning devices

Audible warning devices allow riders of PMDs to provide a warning to other road users who may not be aware of their approach. Judicious use of an audible warning device in shared spaces should allow PMD users to proceed quietly until they need to alert other users to their presence, which can then be done quickly and effectively. This may be especially important when encountering pedestrians who may step into the path of a PMD, unaware of its presence.

Some designs of PMD e.g. hover-boards and e-unicycles may be harder to equip with an audible warning device since they lack a suitable place on which the device or at least its control could be mounted.

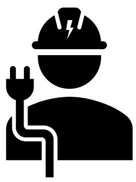
There may be some benefit to fitting 'noise generators' to PMDs, similar to those now mandated for electric cars, which emit a constant warning tone to alert other vulnerable road users to the approach of these otherwise very quiet vehicles. This option may help to prevent collisions between vulnerable road users and PMDs, but brings with it the problem of increased noise pollution.

5.13. Electrical safety



Given the requirement for PMDs to be equipped with a potentially volatile battery and the associated need for charging, electrical safety is an area of considerable concern. Two key issues exist:

- Battery safety in the event of a collision or other damage
- Battery safety during charging



The safety of charging apparatus is covered under the Machinery Directive which regulates the design and manufacture of charging equipment and is intended to ensure that the risk of fire and electric shock from the charging apparatus itself is minimised. There remains however an issue around the safety of the battery pack itself while it is being charged. In particular lithium-ion batteries, which have gained considerable popularity in consumer electronic devices including PMDs, are especially vulnerable to overheating and catching fire while being charged. There is a clear risk associated with increasing numbers of high-capacity batteries being taken into homes for charging, where a malfunction could rapidly lead to a fire that would endanger the property and those within it.

The safety of the battery in the event of it being damaged in a collision or from another impact is also an important safety issue. Lithium-ion batteries in particular are susceptible to catching fire and even exploding if they are mechanically damaged. This obviously has implications for the design of the battery pack and the vehicle structure that surrounds it when batteries are used in vehicles. Vehicles that fall within the scope of Regulation (EU) No 168/2013 are required to have adequate levels of electrical safety which is verified through their compliance with UNECE Regulation 100 and ISO standard 13063, while EPACs are required to comply with the standards set out in CEN15194, but vehicles that are excluded from the scope of this regulation are only required to comply with the less stringent requirements of the Machinery Directive.

In the event of a failure of the electrical system, it is important that the device reverts to a safe state that allows the operator to bring the device to a halt safely. This is an especially important consideration for self-balancing vehicles that rely on their motor control systems to both keep the vehicle upright and to allow it to be steered and stopped. Unlike EPACs, e-scooters or other forms of PMD that do not rely on their electrical systems for their primary control, the electrical systems of self-balancing vehicles must be subject to the same level of design scrutiny that would be given to a steering or braking system, since a failure of the electrical system would have the same result as a failure in one of these equivalent mechanical systems.

Some manufacturers and retailers do reference UL2272, 'Certification for Next Generation Personal e-Mobility'. This certification standard, developed by an established certification body, provides a system level (rather than individual component) based assessment of the electrical and fire safety of PMDs. To attain UL2272 certification, a PMD has to undergo, and successfully pass, a number of electrical, mechanical, and environmental tests that assess electrical safety, and the risk of fire hazard. UL2272 has been developed by UL, who are a private company that develop standards and certifications in a range of fields. UL2272 has not been adopted at a legal level in either the US or the EU, however, new PMDs sold in Singapore since 2018 must comply with UL2272.

5.14. Rearward visibility

For the most part the rearward visibility from PMDs is not inhibited by the structure of the vehicle. However, many forms of PMD suffer from poor rearward visibility due to the difficulty associated with turning to look behind, especially when trying to maintain balance. This may be a particular issue for PMDs that change direction based on the operator leaning, as any twisting or rotating of the body, however slight, may have an impact on steering and direction of travel.

Mirrors are a requirement for vehicles in the L1e-A and L1e-B sub-categories in order to obtain type-approval but other PMDs are not required to be fitted with them. Many of the EPACs and cargo bikes found for sale do come fitted with mirrors, but none of the non-pedal cycle derived types of PMD reviewed in this project had mirrors fitted and in many cases e.g. hoverboards, e-skateboards, e-unicycles etc. there is no convenient place to fit a mirror.

5.15. Device structural integrity

Bicycles including EPACs are required to meet the structural safety standards outlined in ISO4210:2014, which requires extensive safety testing and minimum performance requirements for all key components, and specifies the method for carrying out each structural test. Cycles designed to pedal in L1e-A and B are also in effect required to comply with ISO4210:2014 via Delegated Regulation (EU) 2016/1824[14] which specifies the tests of structural integrity, taken from ISO 4210:2014 that Powered Cycles in L1e-A and cycles designed to pedal in L1e-B must be subjected to (Table 11). Other forms of PMD that fall

[14] Commission Delegated Regulation (EU) 2016/1824 amending Delegated Regulation (EU) No 3/2014, Delegated Regulation (EU) No 44/2014 and Delegated Regulation (EU) No 134/2014 with regard, respectively, to vehicle functional safety requirements, to vehicle construction and general requirements and to environmental and propulsion unit performance requirements

within the scope of CEN17128:2020 are subject to the requirements for structural integrity set out in that standard, which includes tests for both static loading and fatigue along with specific structural test methods for a variety of specific components and systems including forks and handlebars.

Table 11: Test and minimum forces or number of test cycles for vehicles of category L1e-A and cycles designed to pedal of vehicle category L1e-B (Adapted from European Commission, 2016)

Subject	Name of test	Reference of test which shall be used	Minimum value of the required test force or minimum number of test cycles
Handlebar and stem	Lateral bending test (static test)	ISO 4210-5:2014, test method 4.3	800 N
	Fatigue test (Stage 1 — Out of phase loading)	ISO 4210-5:2014, test method 4.9	270 N
	Fatigue test (Stage 2 — In phase loading)	ISO 4210-5:2014, test method 4.9	370 N
Frame	Fatigue test with pedalling forces	ISO 4210-6:2014, test method 4.3	1,000 N
	Fatigue test with horizontal forces	ISO 4210-6:2014, test method 4.4	Number of test cycles = 100,000
	Fatigue test with a vertical force	ISO 4210-6:2014, test method 4.5	1,100 N
Front fork	Static bending test	ISO 4210-6:2014, test method 5.3	1,500 N
Seat post	Stage 1, fatigue test	ISO 4210-9:2014, test method 4.5.2	1,100 N
	Stage 2, static strength test	ISO 4210-9:2014, test method 4.5.3	2,000 N

5.16. Load platforms

Load platforms are the areas available on some types of PMD for the carriage of cargo. Load platform availability and size vary considerably between PMD types. This division tended to follow the logical pattern that smaller devices without suitable space or location for a load platform did not have one at all, while some of the devices that could encompass a load platform within their dimensions did include them or offer them as an option. The sorts of PMDs that tend to feature them are those at the more practical end of the PMD spectrum, for example urban bikes, or seated e-scooters. Offering a load platform on an electrically powered device can make a lot of sense, as it requires limited or no (depending on the device type) additional effort to carry a load as well as the rider – instead it will just reduce range as more battery power will be required to carry the increased mass.

Consideration should be given to the load platform location on the PMD and possible effects on load distribution, particularly under acceleration and braking. In addition, the size and shape of the load that can be accommodated will also be a variable, albeit one largely out of the hands of the manufacturer. If a load platform is able to accommodate loads that are particularly heavy or large in relation to the mass or dimensions of the PMD this may have an impact on safety.

5.17. Stands

Understandably, stands were only found on PMDs that were not intrinsically stable, and with sufficient height in some aspect of the design to require physical intervention to prevent collapse when stationary without a rider.

Most e-scooters identified in the inventory had some form of stand, generally these appear to be spring loaded side stands that allow the scooter to be parked upright at a slight tilt. The other category of PMD that most commonly had a stand as standard was e-bikes, although this tended to vary considerably depending on the intended use case for individual bikes – for example off-road mountain bike style e-bikes often do not have a stand, whereas hybrid or urban style bikes often did – however there was no hard and fast rule in either case, and sometimes a stand would be a cost option offered by the manufacturer.

Of the self-balancing PMDs identified in the inventory, only one was identified with a stand, which was a rear mounted stand that appeared to extend from the standing platform. Self-balancing personal transporters can stand up independently when powered on due to the internal gyros that also allow it to respond to human body movements when in motion. When powered off, a self-balancing personal transporter is longitudinally unstable so either a stand will be required, or it will have to be leaned against something or laid flat. It is likely, given the other options, that most self-balancing personal transporter type devices will have a stand, however this is not identified in the specifications given for those researched for this inventory.

6. Review of personal mobility devices market

A review was conducted of the publicly available market data for PMDs. Data was found e-bikes, including EPACs and cycles designed to pedal in L1e-A and L1e-B, e-cargo bikes and e-scooters. No market data was found for other types of PMD e.g. hover boards.

6.1. E-bike market

Electrically Power Assisted Cycles (EPACs) are pedal cycles with electrical assistance which is restricted to a maximum assistance power of 250W and a maximum assistance speed of 25km/h. EPACs as of 2019 made up 16% (3.3 million units in 2019) of European bicycle sales, as reported by CONEBI (2020).

Figure 12 shows the level of production and sales of EPACs in the EU28, as it was up until the end of 2019 (including the United Kingdom). It shows that levels of production and sales of E-Bikes have been rising exponentially in recent years, particularly since 2017.

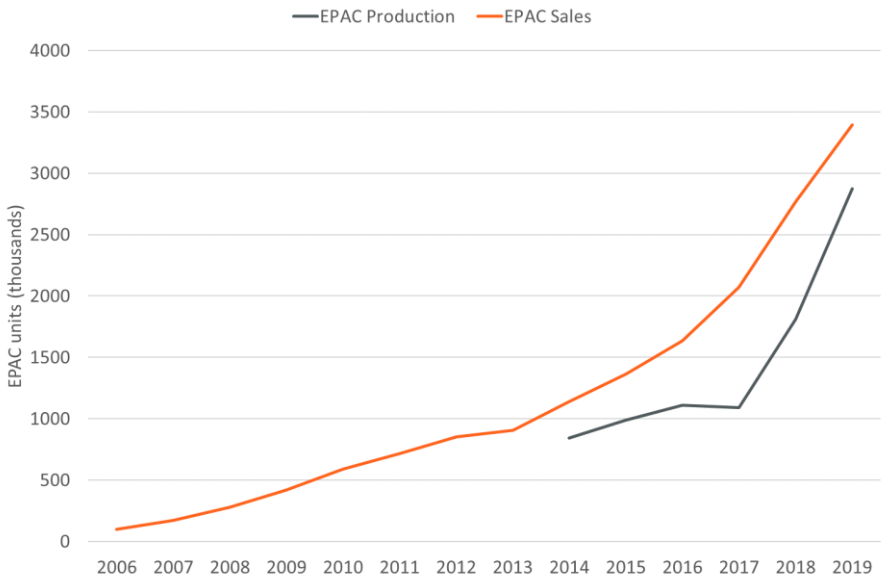


Figure 12: Production (2014-2019) and Sales (2006-2019) of Electrical Pedal Assisted Cycles (EPACs) in the EU28 (Source: CONEBI)

Figure 13 shows the breakdown of EPAC sales in 2019 in the EU28 by member state. It shows that Germany had by far the biggest share of the market (40%), and the five countries with the highest number of sales made up more than three quarters (77%) of the market.

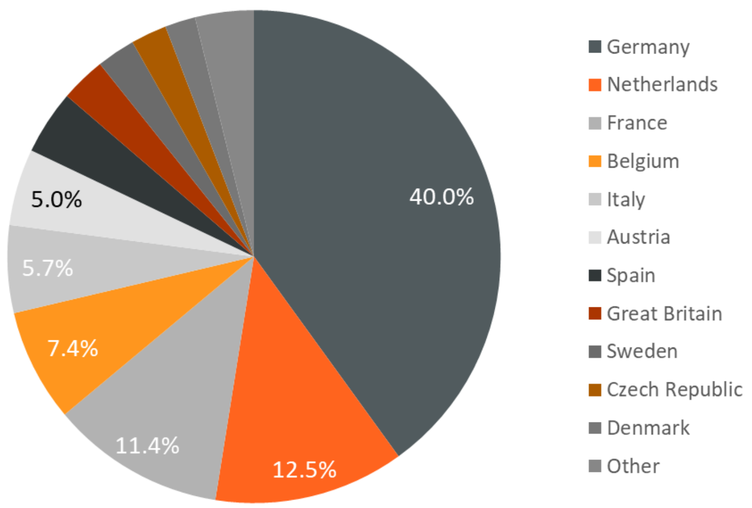


Figure 13: Market share of sales of Electrical Pedal Assisted Cycles (EPACs) in the EU28 by member state, 2019 (Source: CONEBI)

Figure 14 shows the same data, but adjusted for population, based on data from the United Nations (United Nations, 2020). It shows that The Netherlands had the highest number of EPAC sales per million population, followed by Belgium, Austria and then Germany.

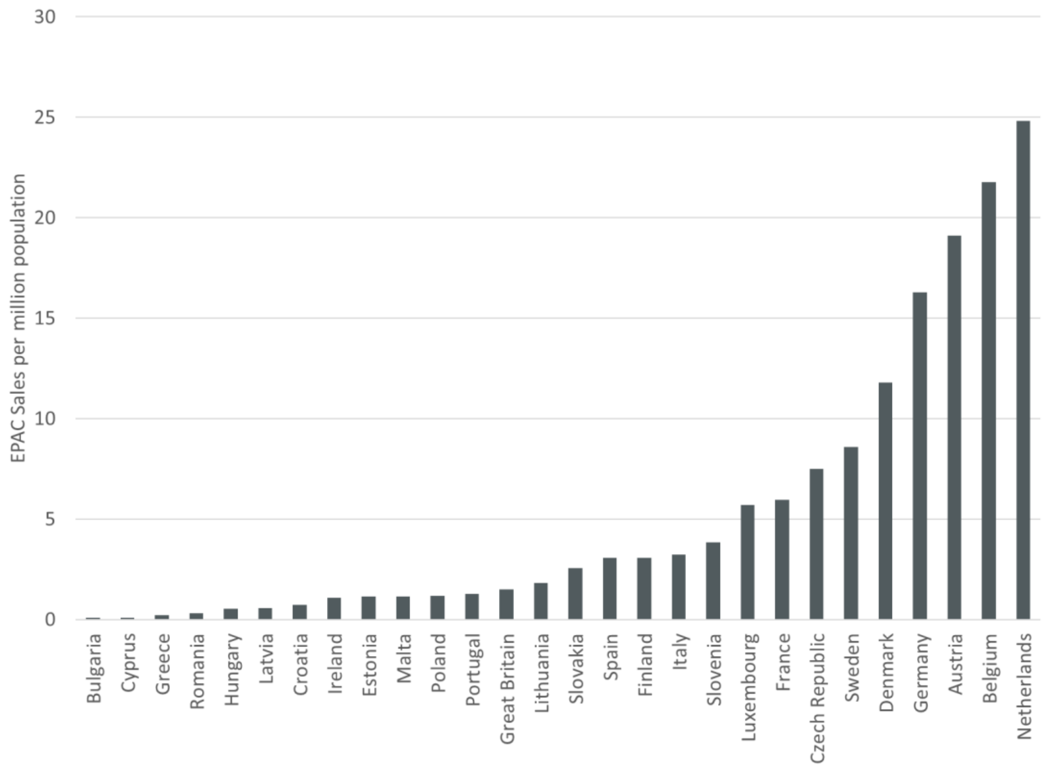


Figure 14: Sales of Electrical Pedal Assisted Cycles (EPACs) per million population in the EU28 by member state, 2019 (United Nations, 2020)

6.2. E-scooter market

In recent years E-scooters have quickly grown in popularity in Europe. The innovation Centre for Mobility and Societal Change (InnoZ) GmbH (2018) observed that between 2017 and 2018, many European countries saw substantial annual growth in e-scooter use, including Poland (1151%), Spain (498%), France (132%), Belgium (415%) and Italy

(286%). Spain and France overtook Germany to become the European countries with the first and second largest market share, respectively.

Data from InnoZ are presented in Figure 15 (market size by country) and Figure 16 (market size by city). It should be noted that these data include non-electric scooters, however these only contribute to 3% of the global scooter fleet, according to InnoZ.

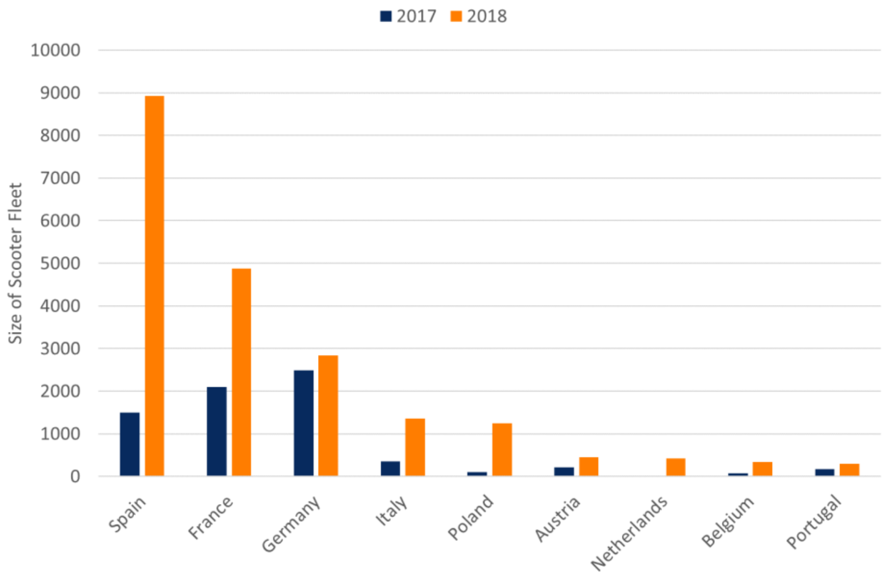


Figure 15: Size of the scooter fleet in nine European countries in 2017 and 2018 (Source: InnoZ)

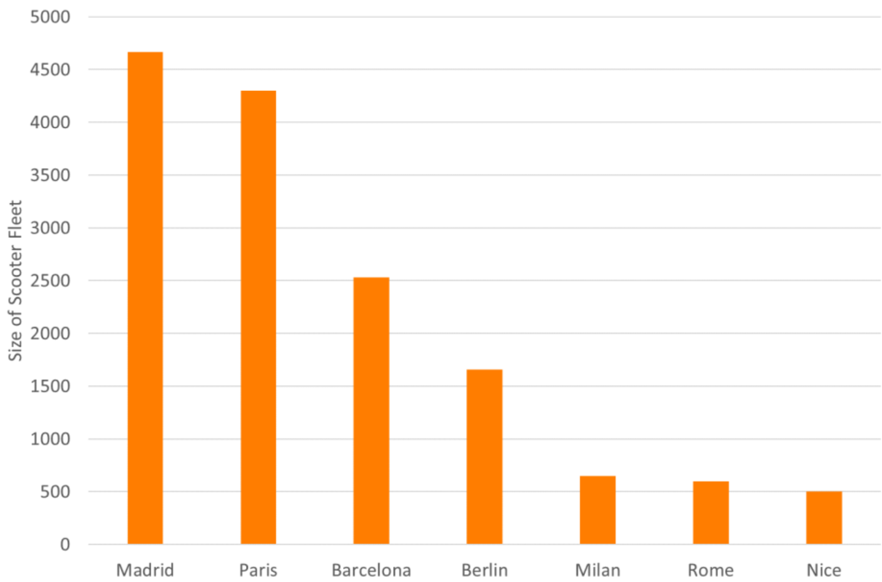


Figure 16: Size of the scooter fleet in the seven European cities with the largest market share, 2018 (Source: InnoZ)

6.3. Cargo bike market

In May 2020, the first ever European cargo bike industry survey was carried out, which surveyed 38 anonymous cargo bike brands (CityChangerCargoBike, 2020). They were asked how many cargo bikes they had sold in Europe in 2018, 2019 and from January-April 2020. They were also asked how many cargo bikes they expected to sell in Europe during the whole of 2020. The results are displayed in Figure 17.

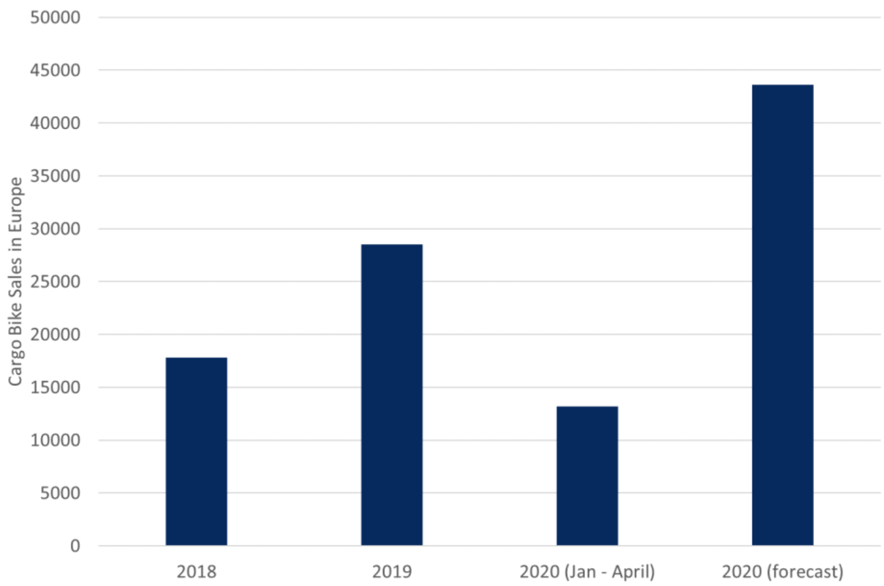


Figure 17: Cargo bike sales in Europe among 38 brands in the industry survey (Source: CityChangesCargoBike)

The data show that despite the impact of the coronavirus pandemic, the cargo bike brands who responded still expected their sales in 2020 to grow by around 53%, although the survey was conducted when the expected duration and overall impact of the pandemic was still uncertain. The survey is due to be repeated in spring 2021, which will confirm whether or not the expected level of growth in 2020 was fully realised.

7. Collision data analysis

This section analyses road traffic collision and injury data, where available, for PMDs to understand the characteristics of PMD collisions. It also attempts to draw comparisons between collisions involving PMDs and other comparable vehicle types. The collision data analysis has been complemented with additional studies where the data is available.

Detailed and comprehensive collision data can provide valuable insights around the safety of micromobility devices. However, in most countries across the EU, micromobility devices are not currently identified within their collision statistics. For instance, according to FERSI Road Safety Research (2020) only seven (out of 18) countries identified e-scooters as a separate vehicle category within their national road accident statistics. Therefore, the majority of the information around PMD-related collisions is derived from media reports. For example, the International Transport Forum (2020) examined the safety of PMDs by drawing information from multiple media articles.

Due to the lack of publicly available information for all countries, a review of online data sources was conducted to identify national databases where PMDs were recorded as a separate category. The review identified three countries (Belgium, France and Germany) as having some national data category for PMDs. This section of the report provides a summary of each dataset for these three countries. However, it must be noted that very limited information was available on the data collection methods for all countries. Furthermore, the majority of the information is provided for e-scooters or e-bikes and there is very little to no information on other PMD categories. It must be also noted that no statistical testing has been conducted due to the large variations in sample sizes, and as such comparisons between countries and vehicles types should be treated as indicative only.

7.1. Summary of data across the EU

The OECD (International Transport Forum, 2020)conducted a review of e-scooter safety. As noted above, the majority of the analysis was summarised from media reports due to lack of detailed collision data around e-scooters. The study found that pedestrians fatalities associated with collision involving e-scooters were rare and similar to pedestrian fatalities associated with collisions involving pedal cyclists. Over 80% of e-scooter and cyclist fatalities were from collisions involving other heavier vehicles. On the other hand, car occupants were more likely to be injured from single vehicle collisions. The study also found that there was no difference in fatality risk between pedal cycles and e-scooters.

The FERSI Road Safety Research Report (2020) asked 18 participating EU countries a range of questions around e-scooters. The majority (14 out of 18) of the countries did identify e-scooters as a separate category within their collision database. Furthermore, 14 countries did not collect any self-reported information about e-scooter related collisions. Of those that did, survey data in Austria found that most conflicts occurred between e-scooter riders and vulnerable road users such as pedestrians or cyclists. It also found that the main reasons for these conflicts were due to carelessness or distraction, disregard of rules and excessive speeding. A pilot study on e-scooters in Norway found that 11% reported at least one collision in 2019 and the majority (86%) of these were single vehicle collisions. This study also found road surface problems (like low surface grip, tramlines etc.) to be the main reason for the collision. When asked about speed behaviour, only Austria had some information and found that e-scooters travelled with a mean speed of 15.1 km/h and maximum speed of 31 km/h. When asked about self-reported information on helmet use, Austria found that only 3% of the e-scooter riders used a helmet while riding. Denmark and Norway reported no helmet obligation.

Schepers et al. (2018) analysed data from two questionnaires commissioned by the Dutch Ministry of Infrastructure and the Environment. The first questionnaire "Survey of bicycle crash victims treated at Emergency Departments" was carried out by The Dutch Consumer and Safety Institute and targeted victims of bicycle crashes seeking information about the crash characteristics and bicycle use before the accident, while the second conducted by KANTAR was sent to 200,000 people at random.

Schepers et al. (2018) showed that when the effect of distance travelled was taken into account, there was no difference between the rate of collisions affecting EPACs and conventional bicycles. They also showed that there was no significant difference in the odds of being admitted to the emergency department between users of EPACs and conventional bicycles.

In collisions in which another vehicle was involved EPACS accounted for fewer cyclist collisions than conventional bicycles; 33% (n = 588) of conventional bicycle collisions involved another vehicle, while only 23% (n = 132) of EPAC collisions involved another vehicle.

Hertach et al. (2018) observed that in Switzerland, which has categories of electrically assisted bicycles analogous to L1e-A and cycles designed to pedal in L1e-B, the most common cause of collisions was skidding. They also concluded that higher riding speeds were strongly associated with a higher risk of moderate to severe injury.

7.2. Belgium

This section analyses road accident casualty data for 2019 are available online[15] through an open-source website. Although there was more information available on the collision itself, it was not possible to link the casualty data to the collision data. Therefore, the analysis has been limited to casualty data from 2019. Belgian casualty data comprises of information on area type, road user type, lighting conditions, casualty age and gender.

There were 47,092 casualties from all road collisions in 2019. Of the total, there were 16,535 (35%) casualties from two-wheeler vehicles. The distribution is presented in Table 12.

Table 12: Number of casualties by vehicle type in Belgium (2019)

Vehicle type	Number of casualties	Proportion of casualties
Bicycle	8,487	18%
EPAC (<250W motor power, <25km/h max speed)	1,767	4%
Cycle designed to pedal in L1e-B (<45km/h max speed)	197	<1%
Moped (<25km/h max speed)	65	<1%
Moped (<45km/h max speed)	3,110	7%
Motorcycle	2,909	6%
Total	**16,535**	**35%**

Overall, bicycles accounted for the highest number of casualties. EPACs and cycles designed to pedal in L1e-B account for less than 5% of the total number of casualties,

[15] Source: https://statbel.fgov.be/en/open-data?category=162&page=0

however, this may be due to the lower number of PMDs being used on road compared with bicycles. Figure 18 presents casualty severity by vehicle type.

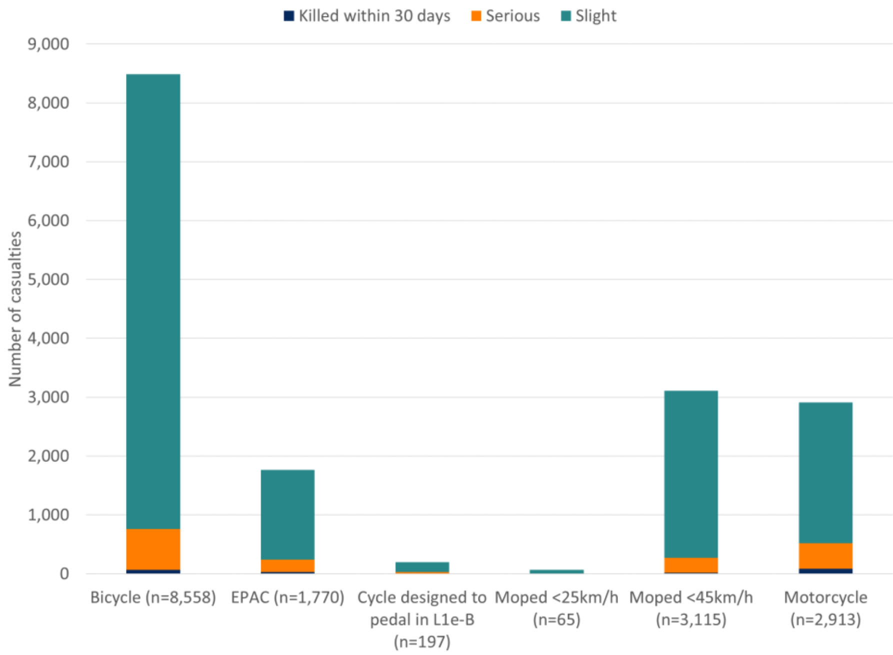


Figure 18: Number of casualties by severity and vehicle type in Belgium (2019)

The majority of the casualties were slightly injured. Motorcycle casualties had the highest proportion of fatalities (84 killed) when compared to the other vehicles. Cycles designed to pedal in L1e-B and EPACs had a higher proportion of casualties that were seriously injured (about 13%) when compared to bicycles and mopeds (around 8%).

A comparison of casualties by vehicle type and area is shown in Figure 19.

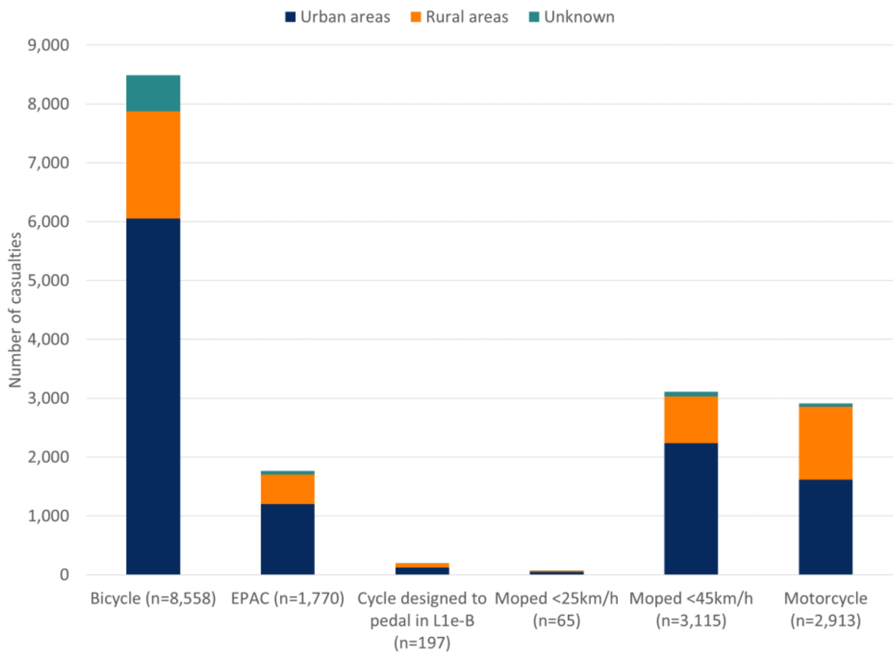


Figure 19: Number of casualties by area and vehicle type in Belgium (2019)

Over 50% of the casualties were in urban areas for all vehicle types, with bicycles and mopeds having the highest proportions of around 70%.

The number of casualties by light conditions and vehicle type is shown in Figure 20.

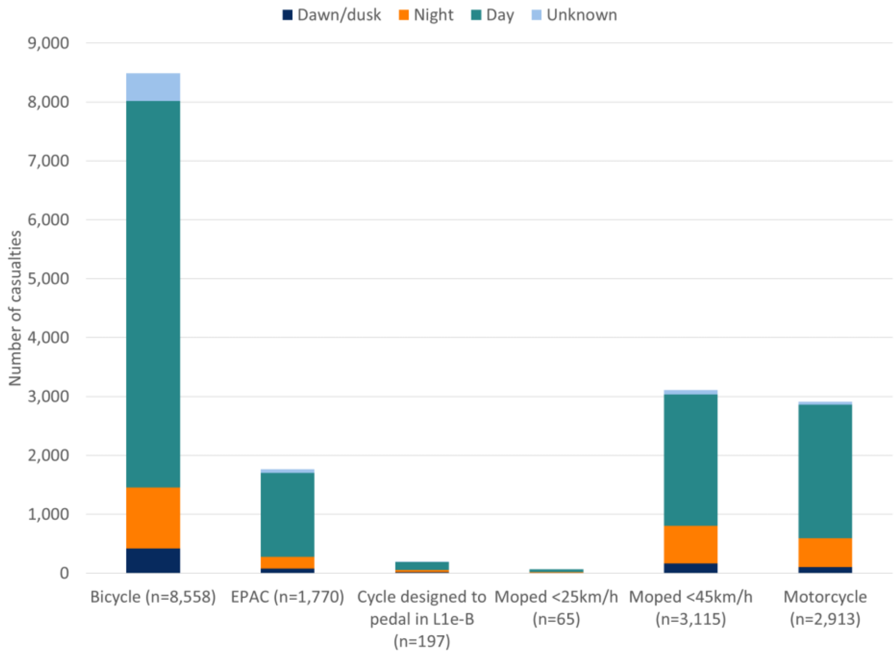


Figure 20:Number of casualties by light conditions and vehicle type in Belgium (2019)

The majority of the casualties (around 70%) occurred during the day for all vehicle types. Around 20% of the casualties involving cycles designed to pedal in L1e-B and 20% involving mopeds occurred at night-time, and 11% of the casualties from EPACs and bicycles occurred at night-time.

Figure 24 presents the number of casualties by age group.

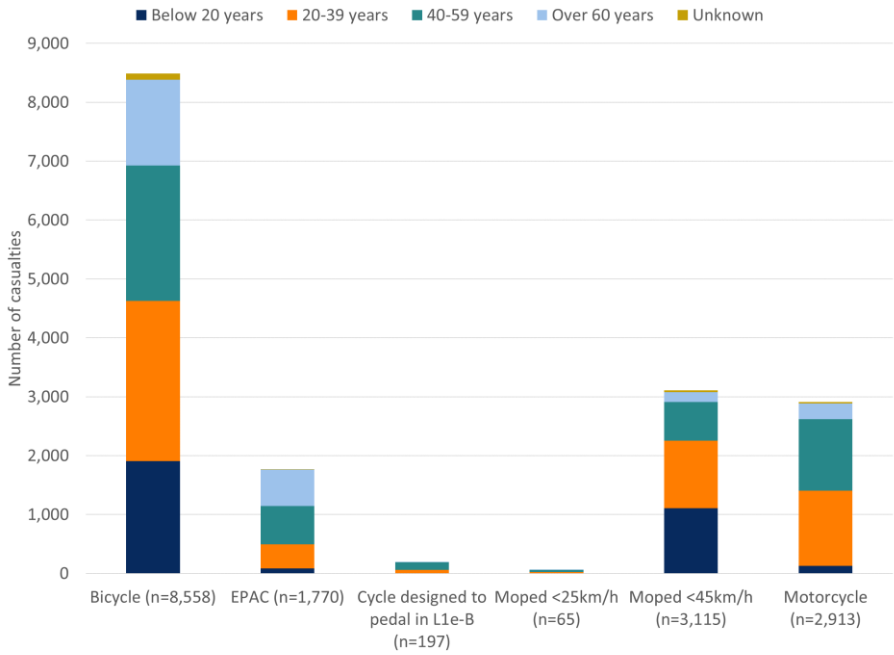


Figure 21: Number of casualties by age group and vehicle type in Belgium (2019)

The age distribution was fairly uniform across all vehicle types. The casualty distribution by gender is shown in Figure 25.

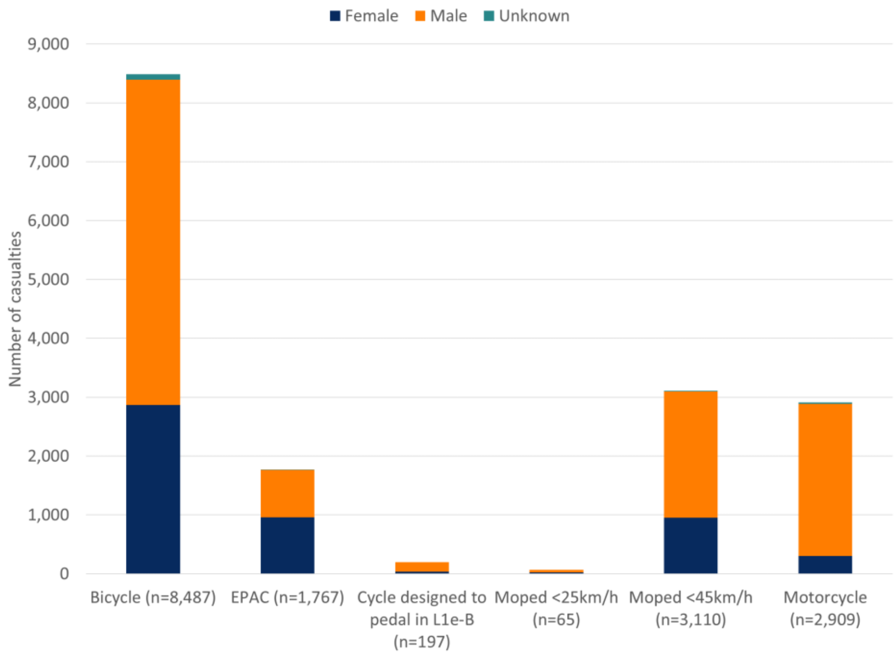


Figure 22: Number of casualties by gender and vehicle type in Belgium (2019)

Around 55% of the casualties from collisions involving EPACs were female, the highest of all vehicle types shown above. For the other vehicle types, the majority of the casualties were male.

7.3. Germany

The German Federal Statistical Office (Destatis) report summary data on road traffic collisions by various factors. This section presents a summary of those factors that relate to PMDs.

Destatis provides a comparison of collisions involving e-scooters and bicycles between January and June 2020[16]. This is presented in Table 13.

Table 13: Comparison of collisions by vehicle type in Germany

Vehicle type	Number of collisions involving personal injury
Bicycle	39,570
E-scooters	654
All vehicles	**118,843**

The numbers above highlight the number of collisions where the user had an injury. The analysis below presents a distribution of casualties.

A comparison of casualties associated with these collisions, along with casualty severity is presented in Figure 23 below.

[16] https://www.destatis.de/EN/Themes/Society-Environment/Traffic-Accidents/Tables/e-scooter.html

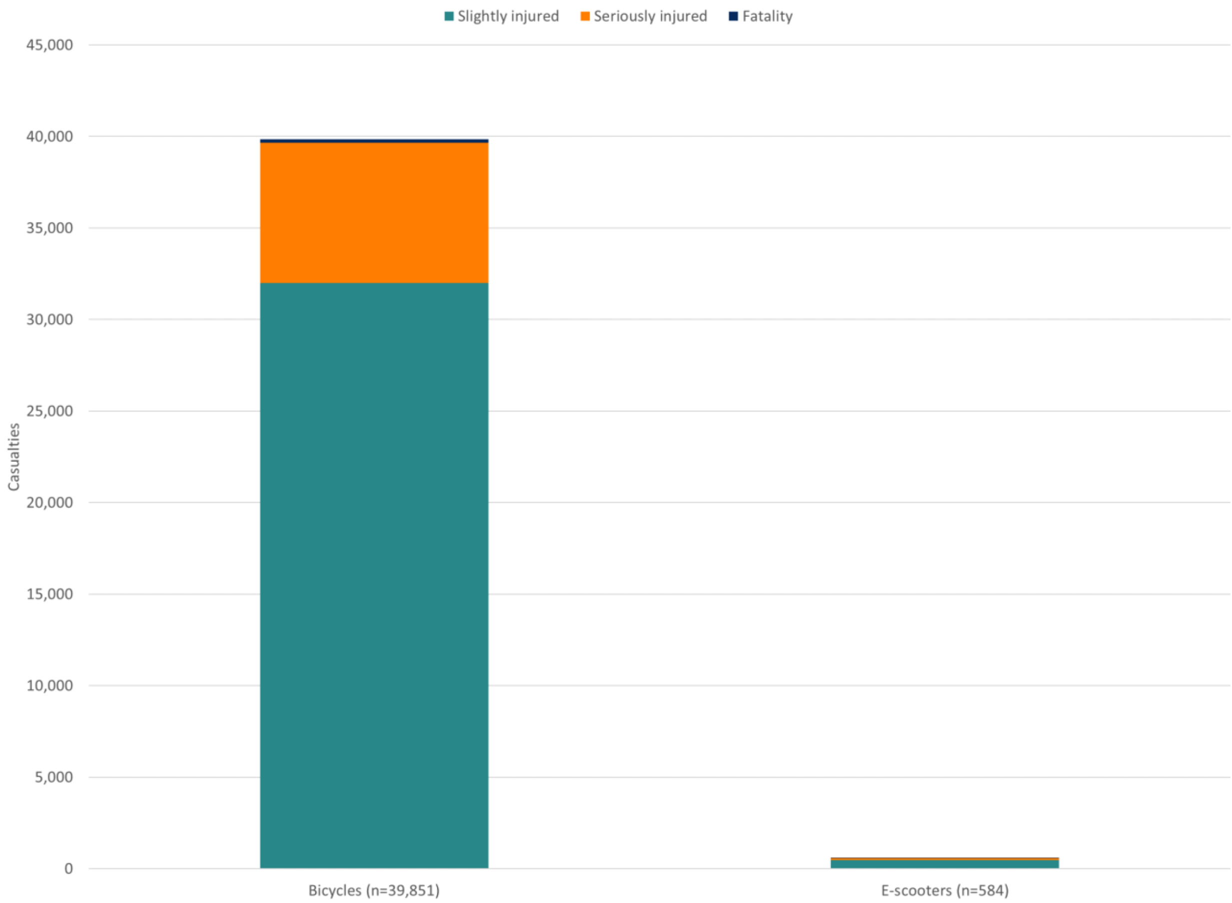


Figure 23: Casualties by severity and vehicle type injured while riding bicycles and e-scooters in Germany in January – June 2020

There is no difference in the distribution of casualty severity between e-scooters and bicycles. In both cases, fatalities accounted for less than 1% of the casualties, serious injuries account for around 20% and the remaining 80% are slightly injured casualties. It must be noted that only six months of data were used for this comparison and multiple factors such as seasonality and impact of COVID-19 could influence the results.

Destatis also comprised of casualty data on two-wheeler vehicles from 2014 to 2019. Figure 24 presents the distribution by severity for 2019 data and Figure 25 shows the distribution of killed or seriously injured casualties from 2014 to 2017 to enable comparisons over time.

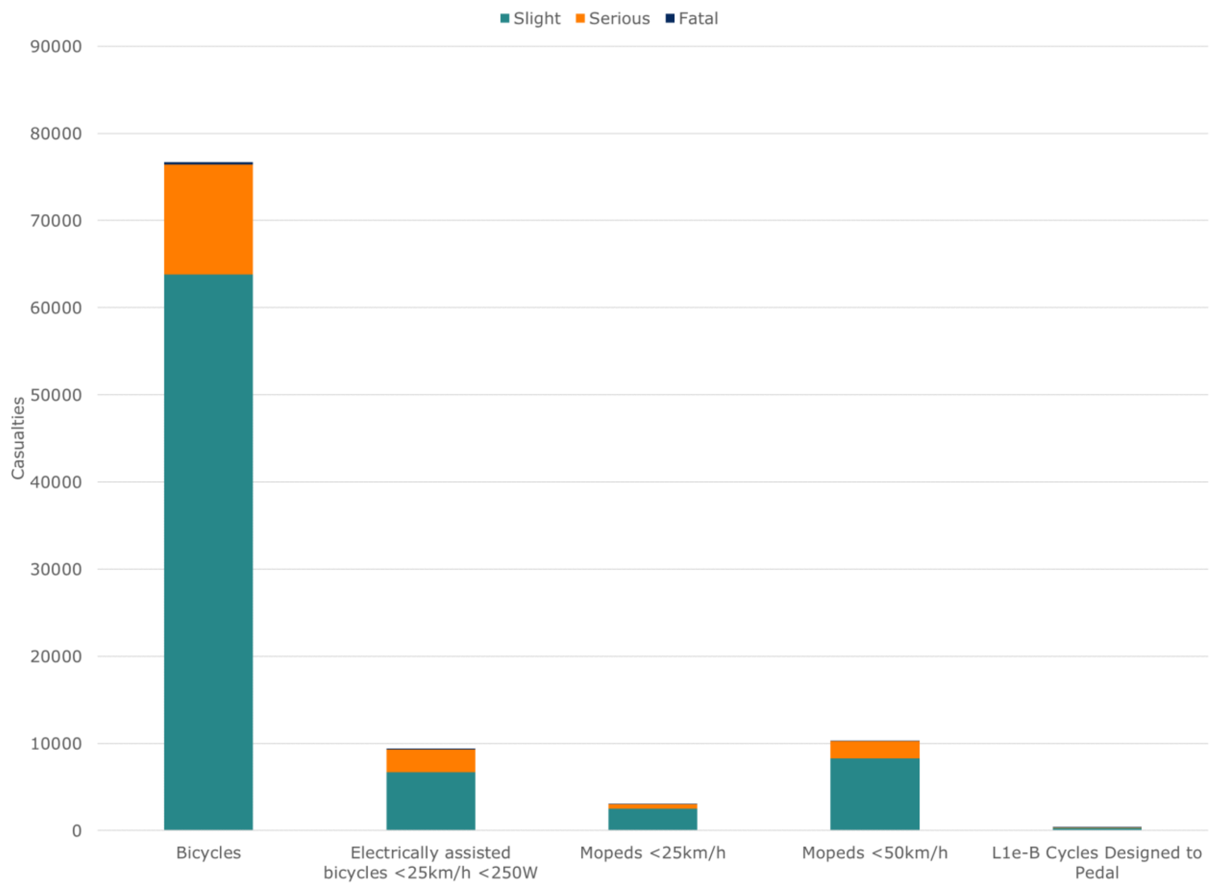


Figure 24: Casualties by severity and vehicle type in Germany (2019)

The proportion of fatalities were less than 1% across all vehicle types and the majority (over 70%) of the casualties were slightly injured. The proportion of casualties seriously injured were the highest (25%) for electrically assisted bicycles (below 25 km/h), followed by cycles designed to pedal in L1e-B (23%).

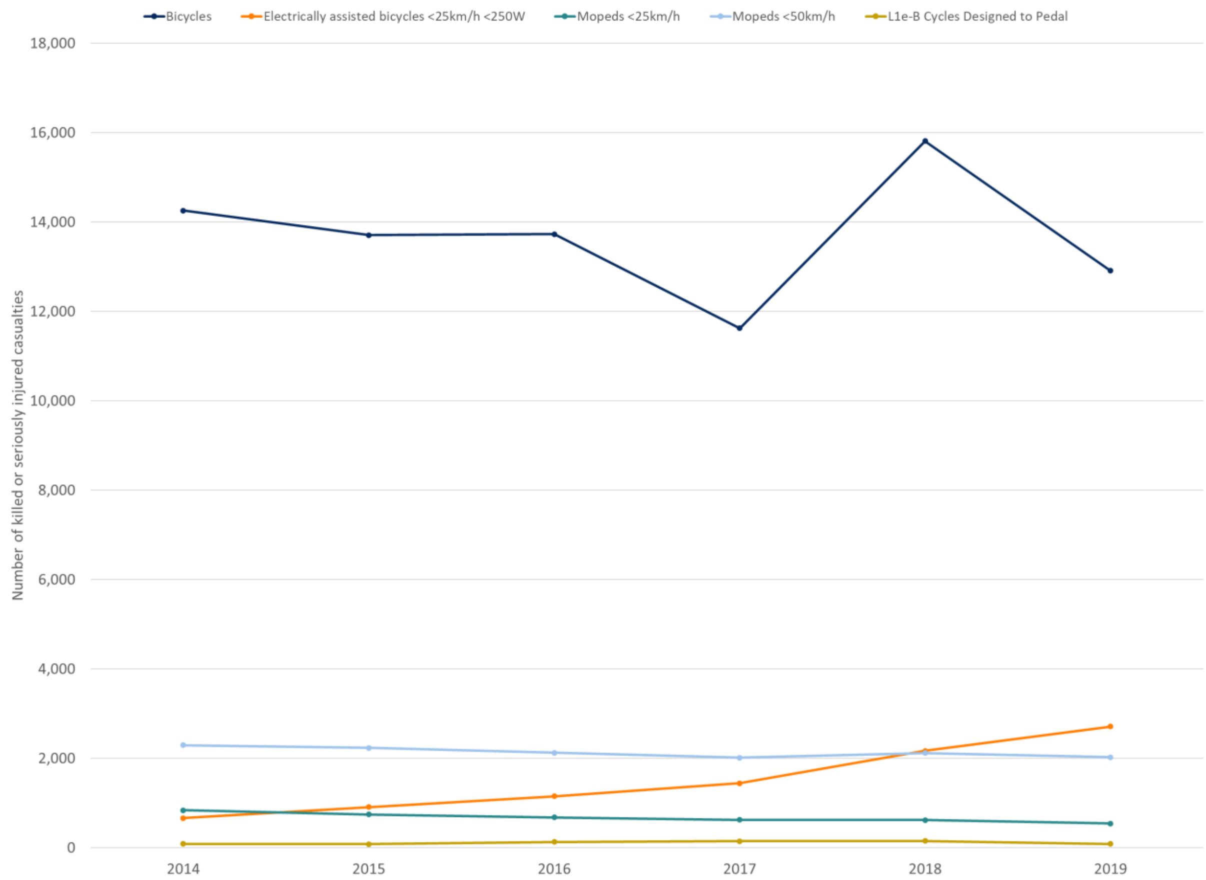


Figure 25: Number of killed or seriously injured casualties over time in Germany

When looking at killed or seriously injured (KSI) trends over time, there was a 9% decrease in bicycle KSIs between 2014 and 2019. On the other hand, electrically assisted bicycle KSI casualties increased by more than three times from 663 to 2,714 KSIs. These figures most likely reflect a shift from conventional pedal cycles to electrically assisted alternatives and should not therefore be interpreted as growing risk to electrically assisted cyclists. However, cycles designed to pedal in L1e-B remained almost constant with 87 KSIs in 2014 and 85 in 2019. The two moped categories have reduced slightly by 24%, on average.

7.4. France

Road traffic collision data for France was available from the open source government website[17]. From 2018, the collision data classified pedestrians on roller skates or on scooters as 'personal travel'. This was included in the collision data categorised as 'other vehicles'. However, it is not possible to distinguish between these personal travel vehicles and any other vehicles that may be included in that category such as emergency vehicles for instance. Therefore, any conclusions drawn from the analysis below may be limited.

In 2018, there were 98,876 vehicles involved in collisions across France. Of these,778 vehicles (around 1%) were vehicles involving other vehicles such as PMDs. There were 818 casualties associated to these other vehicles involving PMDs.

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17 https://www.data.gouv.fr/fr/datasets/base-de-donnees-accidents-corporels-de-la-circulation/#_

The distribution by casualty severity, along with comparisons to cyclist and moped casualties, is presented in Figure 26.

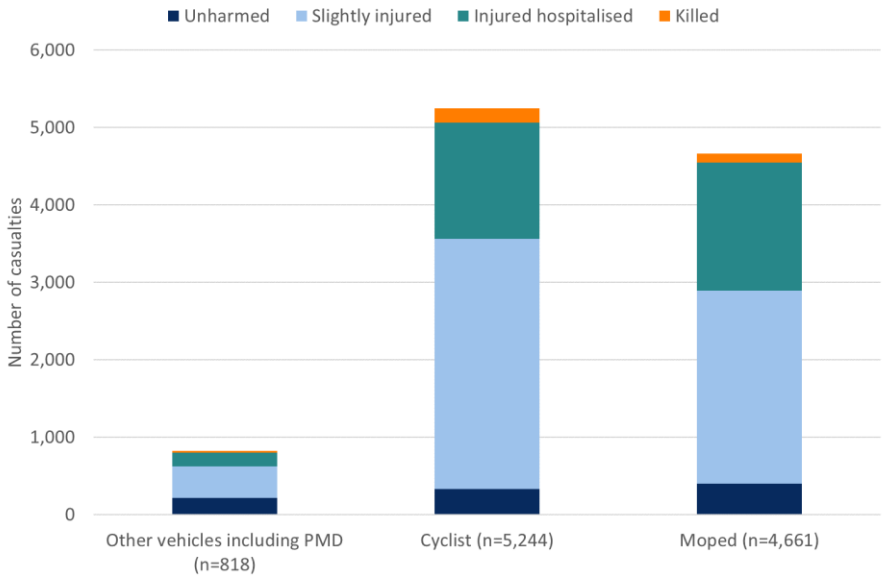

Figure 26: Number of casualties by severity and vehicle type in France (2018)

Around 38% of moped and 32% of cyclists involved in collisions were either killed or seriously injured, and about 24% of other vehicle operators including PMD users involved in collisions were killed or seriously injured. However, it must be noted that other vehicles could include a wide range from emergency services to vehicles drawn by animals. The distribution of casualties by journey purpose is presented below.

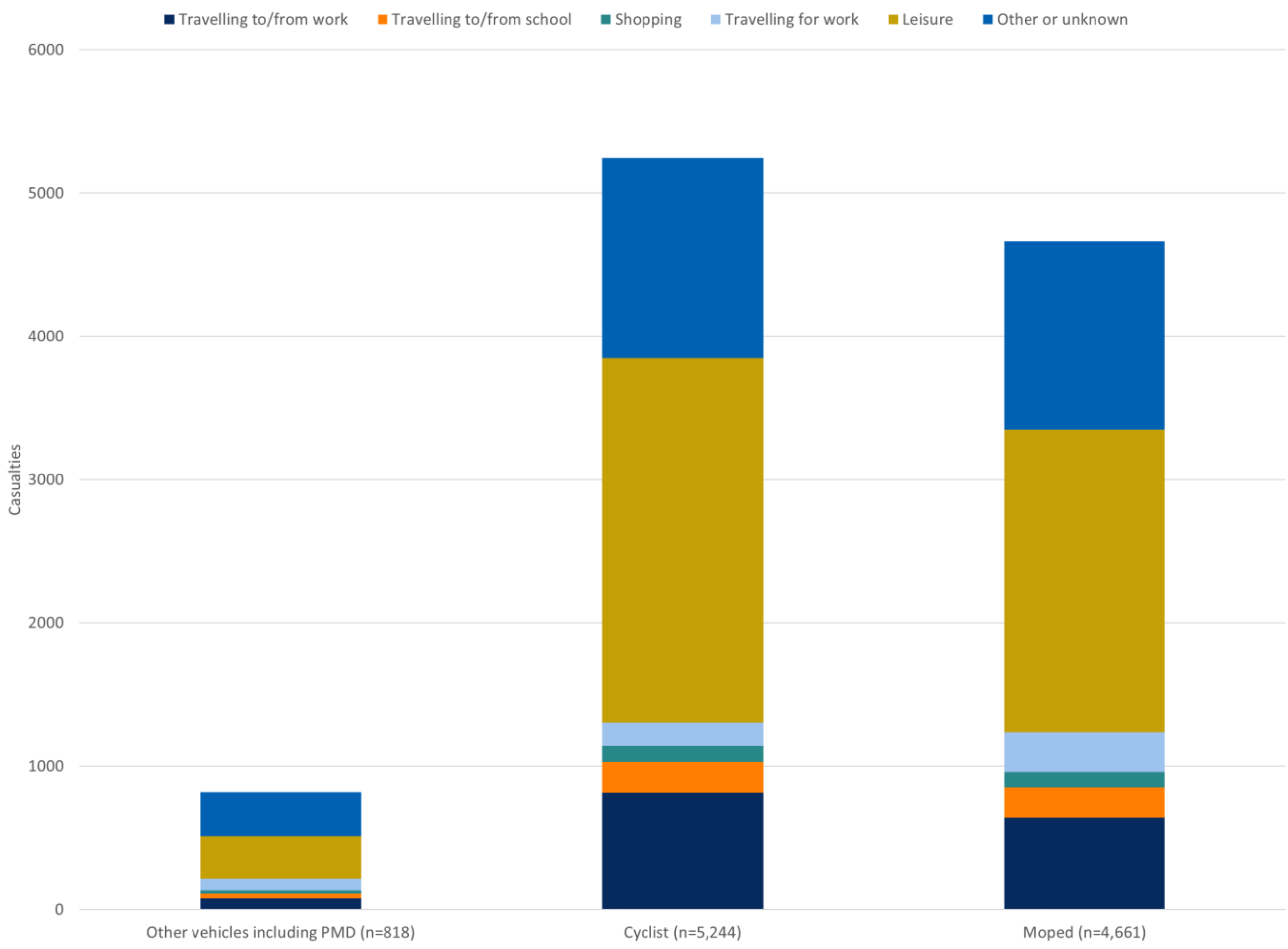

Figure 27: Number of casualties by journey purpose and vehicle type in France (2018)

Excluding unknowns, leisure activity was the journey purpose that led to the greatest number of casualties, accounting for 35% of the casualties across all vehicle types.

8. Case studies

In this section we present four case studies which illustrate the range of regulatory approaches taken to PMDs and market information on those devices. In each case, we focus attention first on the market across the EU28, and then specifically on two countries within the EU. In each case the countries chosen represent either the largest market for a particular group of vehicles or contrast significantly in the manner in which those vehicles are regulated.

8.1. Case study 1: Electrically assisted pedal cycles (EPACs) which are outside the scope of Regulation (EU) No 168/2013, i.e. <250W, <25km/h.

The technical characteristics of these vehicles are subject to CEN standard 15194 which is applied under a self-certification scheme by manufacturers and importers.

The road circulation regulations applied to these vehicles are typically the same as those applied to conventional pedal cycles.

These vehicles provide a good example of 'light-touch' regulation applied to both manufacturers and users. The market for these vehicles is also relatively large and mature and consequently has good quality market and safety data available.

8.1.1. Market Across the EU28

There is a good level of market data available, but no EU-wide collision data, as only certain countries are able to provide separate collision information for EPACs or other electric bicycles.

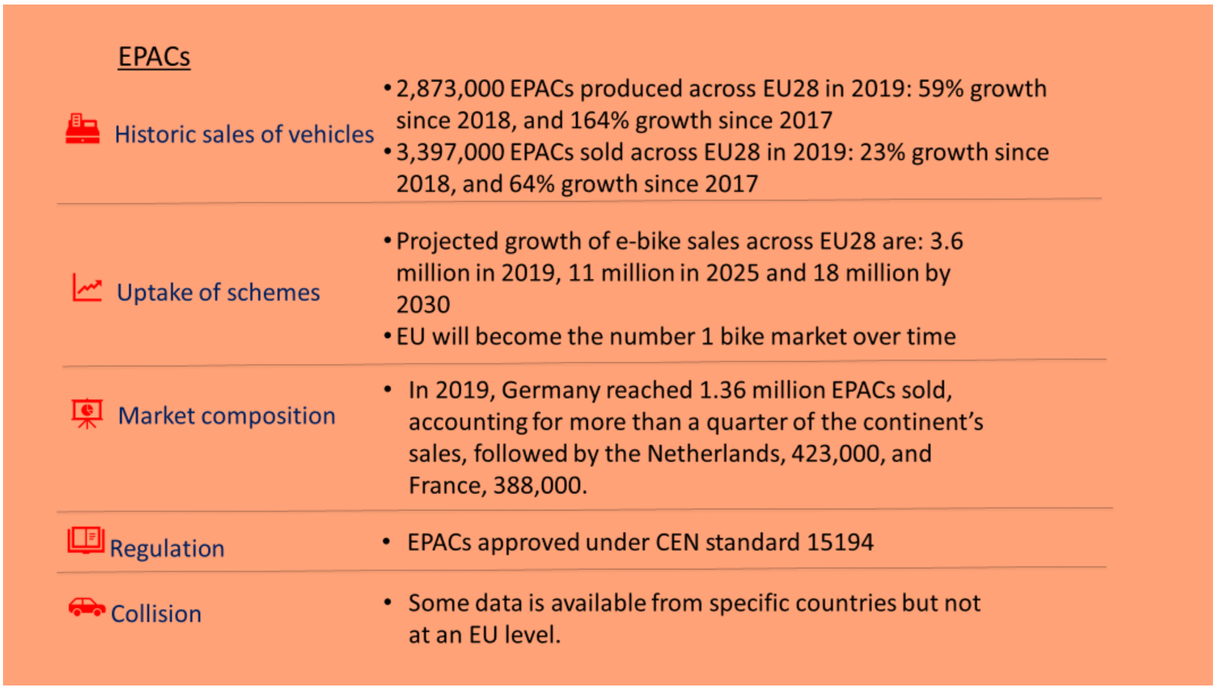

Figure 28: Summary of the EPAC market across the EU (Sources: CONEBI – Confederation of the European Bicycle Industry; Cycling Industries Europe)

8.1.2. *Market in Belgium and Germany*

The two countries apply the same EU-wide regulatory framework to EPACs, but in the most recent available year of data (2019), Germany saw a large increase in sales, whereas Belgium saw a levelling off / slight decrease.

EPACs	Belgium	Germany
Historic sales of vehicles	• Around 251,000 in 2019 • Sales of electric bicycles fell by 4% from 2018	• Around 1,360,000 in 2019, a growth of 39% from 2018
Uptake of schemes	• Main users are younger population (between 30-50 years) • Increasingly used for commuting	• Used for both work and leisure purposes
Market composition	• EPAC sales constituted 33% of all sales of bicycles in 2019	• EPAC sales constituted 31.6% of all sales of bicycles in 2019
Regulation	• Follows EU CEN standard 15194	• Follows EU CEN standard 15194
Collision	• Collected in national database from 2017 • In 2019, there were around 1,770 casualties from collisions involving e-bikes	• Collected in national database from 2019

Figure 29: Summary of the EPAC market in Belgium and Germany (Sources: CONEBI – Confederation of the European Bicycle Industry; TRAXIO; StatBel; DESTATIS)

8.2. Case study 2: Cycles designed to pedal in L1e-A and B, also known as Speed Pedelecs, which are within the scope of Regulation (EU) No 168/2013, i.e. >250W.

The technical characteristics of these vehicles are subject to Regulation (EU) No 168/2013, which is enforced through type-approval.

The road circulation regulations applied to these vehicles are typically similar to those applied to mopeds in the L1 category.

These vehicles therefore provide a good comparative example to Case Study 1 and represent a stricter approach to the regulation of both manufacturers and users. The market for these vehicles is relatively mature compared to other types of PMD and consequently has good quality market and safety data available.

8.2.1. *Market Across the EU28*

There is a lower level of market information available at an EU level, compared with EPACs, due to the relative size and infancy of the Speed Pedelec market.

Cycles designed to pedal in L1e-B	
Historic sales of vehicles	• Data is not available at an EU level. • Sales estimated to be around 20,000-25,000 in 2019 (1% of e-bike sales)
Uptake of schemes	• Unknown
Market composition	• Estimated to be a small market (1% of e-bike sales)
Regulation	• Approval and market surveillance of two- or three-vehicles and quadricycles • Environmental and propulsion unit performance requirements • Vehicle functional safety requirements • Vehicle construction and general requirements • Administrative provision • General product safety and Battery Directive
Collision	• Some data is available from specific countries but not at an EU level.

Figure 30: Summary of the Speed Pedelec market in the EU28 (Sources: CONEBI – Confederation of the European Bicycle Industry; International Transport Forum)

8.2.2. Market in Belgium and The Netherlands

The speed pedelec markets in both Belgium and the Netherlands are both fairly small but growing at a significant rate. Belgium has a slightly younger demographic of users on average.

Cycles designed to pedal in L1e-B	Belgium	Netherlands
Historic sales of vehicles	• Total fleet size of over 29,000 at the end of 2019, including around 13,000 new registrations	• Total fleet size of 21,100 as of 1st July 2020, around double what it was 3 years previously
Uptake of schemes	• Main users are younger population (between 30-50 years) • Increasingly used for commuting	• Average age of speed pedelec owners: 51.5 years old (1st July 2020) • 66% of owners aged 45-65

Market composition	• Of new registrations in 2019:
	  • 52% privately owned
	  • 31% registered by a leasing company
	  • 17% registered by another company
		• Unknown

Regulation	• Devices permitted on the road, but not on pavements • Helmet required for certain devices • Insurance, license, license plate, reflectors and mirrors required	• Permitted on 'extra urban' cycle paths, but not on other cycling infrastructure • Helmet required for certain devices • Insurance, license, license plate, reflectors and mirrors required
Collision	• Collected in national database from 2017	• Unknown

Figure 31: Summary of the Speed Pedelec market in Belgium and the Netherlands (Sources: CONEBI – Confederation of the European Bicycle Industry; LEVA-EU; TRAXIO; StatBel)

8.3. Case study 3: Personal light electric vehicles including e-scooters, self-balancing personal transporters, hover boards etc.

The technical characteristics of these vehicles are primarily governed by the Machinery Directive, but some Member States e.g. Germany, have devised national technical standards for some types in this category.

The road circulation regulations applied to these vehicles vary significantly between member states with some, e.g. Sweden, treating them in the same way as they treat conventional pedal cycles, and others, e.g. France, treating them like mopeds.

These vehicles offer an illustration of the variability that can develop when new types of vehicle are introduced in a short time scale with limited opportunity for regulators to react. These vehicles are also unusual in that large rental fleets make up a significant proportion of the vehicles on the road.

This case study focusses specifically on the market for e-scooters, as there was a lack of available data or information for other personal light electric vehicles.

8.3.1. Market Across the EU28

There is currently no formal registration process for e-scooters, which has a negative impact on the amount of market data available.

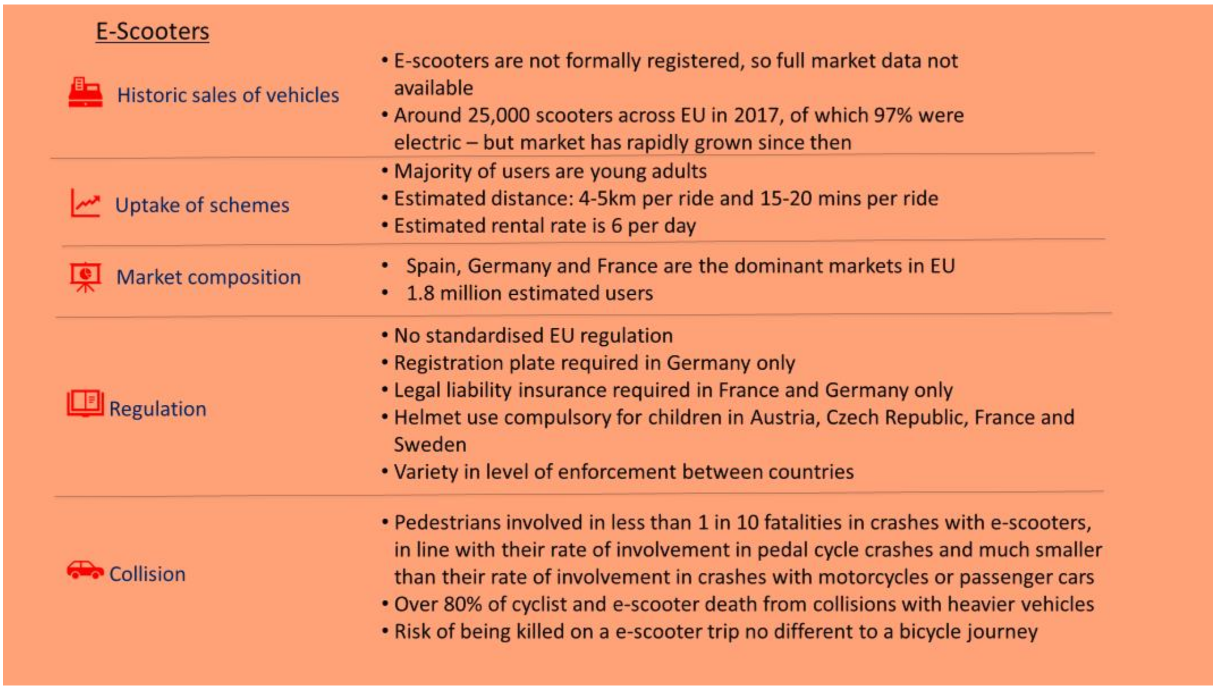

Figure 32: Summary of the E-Scooter market across the EU (Sources: FERSI Road Safety Research; International Transport Forum; InnoZ)

8.3.2. Market in Sweden and Germany

Germany has a considerably larger, more established market than Sweden.

E-Scooters	Sweden	Germany
Historic sales of vehicles	• Estimated 17,000 in 2019, including around 9,000 in Stockholm	• Around 550,000 in 2019
Uptake of schemes	• Main users are young adults • Journey purpose is for work/school trips	• Main users are young adults • Journey purpose differs by ownership. Shared e-scooters are used for leisure purposes; privately owned for school/work purposes.
Market composition	• Not formally registered. • Estimated to be around 17,000 summertime rental e-scooters	• Not formally registered. • Estimated to be around 500,000 private and 50,000 shared
Regulation	• Depends on the power of the e-scooter, otherwise same legislation as bikes. • No age restrictions • No legal liability insurance needed	• E-scooters are a dedicated category, similar to light moped and bicycles • Must have a registration plate • Age restrictions apply • No legal liability insurance needed • No legislation on parking
Collision	• Jan-Oct 2019: almost 500 accidents involving E-scooters reported • 1 fatality in May 2019, e-scooter night-time collision with car • No separate category in collision database	• Jan-Sept 2020: 1,570 accidents, 7 killed, 269 seriously injured, 1,096 lightly injured • Captured in certain main cities from 2020. • In 2019, Cologne estimated around 104 collisions involving e-scooters.

Figure 33: Summary of the E-Scooter market in Sweden and Germany (Sources: FERSI Road Safety Research; DESTATIS; VTI)

8.4. Case study 4: Electrically assisted cargo bicycles, tricycles and quadricycles

This group of vehicles spans across both the category of vehicles that are below 250W/25km/h and hence out of scope of Regulation (EU) No 168/2013 and many of the L categories including L1, L2 and L6.

These vehicles offer examples of the challenges involved in integrating new designs of vehicle into the existing structure of the L category. They also offer examples of the extremes of design that may be seen in terms of both size and mass in the field of light electric vehicles. These vehicles also provide an opportunity to discuss the ways in which commercial operators are adopting light electric vehicles to replace combustion engine vans for 'last mile' deliveries.

Given the relatively small numbers of these vehicles currently in operation there is limited market and safety data available. However, we worked with Cycling Industries Europe to collect data from fleet operators to collate some indicative statistics for this market. These data primarily look at the Cargo Bike market as a whole across the EU, and so a much more detailed amount of information is available at this higher level.

8.4.1. Market Across the EU28

Cargo Bikes	
Historic sales of vehicles	• Among major EU manufacturers, sales in 2019 were 60% higher than 2018, and predicted to increase by a further 53% in 2020 • Market is estimated to reach around 1 million units by 2030 (5% of e-bike sales)
Uptake of schemes	• No current evidence of any shared mobility schemes being used
Market composition	• An estimated 97% of cargo bikes are used to deliver goods/services, and only 3% used to transport passengers • An estimated 62% of bikes are fully electric. The remainder of the fleet is either mixed power or non-electric
Regulation	• To date, no cargo bikes have gone through type approval
Collision	• No reports of any cargo bike fatalities • Estimated 3-4 serious injuries and 14-19 minor injuries per 1 million km of riding

Figure 34: Summary of the market for Cargo Bikes across the EU (Source: Cycling Industries Europe)

8.4.2. Market in France and Germany

There is very little information available about the Cargo Bike market in specific countries.

Cargo Bikes	France	Germany
Historic sales of vehicles	• 8 manufacturers surveyed, average of 4 cargo bikes per fleet	• 22 manufacturers surveyed, average of 12 cargo bikes per fleet
Uptake of schemes	• No evidence of shared schemes	• No evidence of shared schemes
Market composition	• Unknown	• Unknown
Regulation	• No level of regulation / type approval	• No level of regulation / type approval
Collision	• No reported fatalities, injury rates unknown	• No reported fatalities, injury rates unknown

Figure 35: Summary of the market for Cargo Bikes in France and Germany (Source: Cycling Industries Europe)

9. Stakeholder engagement

As part of this project, we sought to explore views and reach consensus among stakeholders on a shortlist of potential regulatory measures for PMDs, including consideration of the estimated potential cost-benefit relationships of those measures.

This section describes the method of engaging stakeholders for this study, and the findings from the stakeholder engagement activities. Overall, this study was conducted in three main steps:

1. Stage 1 of the Delphi panel, whereby stakeholders suggested regulatory measures for the safe use of PMDs (via an online survey)

2. Stage 2 of the Delphi panel, whereby stakeholders rated the suggested potential regulatory measures from Stage 1 of the Delphi panel (via an online survey)

3. Two remote stakeholder workshops, whereby stakeholders provided supporting or opposing evidence (either anecdotal or empirical) for the suggested potential regulatory measures from Stage 1 of the Delphi panel

The desired overall outcome was to reach consensus on which measures are most worthy of prioritisation. It is worth noting that prioritisation of measures was based predominantly on expert judgement rather than empirical evidence. For example, a full cost-benefit analysis could not be conducted for any of the measures as part of this study, as stakeholders were asked to use their judgement to assess relative costs and effectiveness. Therefore, outcomes of this study should be interpreted with caution.

9.1. Method

9.1.1. Selection of the data collection method

The Delphi technique involves recruiting a panel of experts, and collecting and synthesising informed opinion on a specific topic or area. The process is a mixed methods approach (using both qualitative and quantitative techniques) and involves a number of iterations of carefully constructed surveys. Expected outcomes of this iterative process are that the range of answers provided by participants will decrease, and the group will converge towards consensus.

This technique was selected for this study because it facilitates collation of several rounds of opinion from a range of expert participants, avoids the problem of 'group think' (a type of behaviour which can be exhibited by groups whereby they reach a perceived consensus on the majority view, without critically thinking or testing alternative hypotheses), and is argued to encourage critical thinking and a more open debate.

Following the Delphi panel, two remote workshops were conducted with the stakeholders to obtain supporting or opposing evidence (either anecdotal or empirical) for the suggested potential regulatory measures gathered during the Delphi panel.

The Delphi technique and workshops were well-suited to remote engagement with stakeholders, which was useful given the COVID-19 pandemic restrictions at the time of the study. Remote engagement also made the study more accessible by a larger number of participants, and by a more diverse range of participants (e.g. those from different regions of the UK or other countries).

Further details of how the Delphi panel and workshop were facilitated for this study are provided in Section 9.1.4.

9.1.2. Ethics and data protection

This proposed stakeholder engagement method was reviewed by TRL's ethics panel before any stakeholders were contacted about the study. An Information Sheet was provided to stakeholders before the study (including information about the study and how their data will be collected and used), so that they could provide their informed written consent before participating. Participants were also reminded at several points during the study that they could withdraw at any time without providing a reason.

The personal data we collected and used for this study were names and email addresses of stakeholders (so that we could provide them with information about the research and arrange their participation), and video and audio recordings of the workshops. Video recordings of the workshops were securely deleted immediately after each workshop, whereas the audio recordings of the workshops were used for analysing workshop discussions.

9.1.3. Participants

Prior to the study, we obtained the contact details of approximately 230 stakeholders from our professional networks, a list of those who attended a webinar as part of the wider project, LinkedIn communications, and company websites. During the course of the study, we obtained contact details of additional stakeholders who expressed their interest in participating or who were nominated by other stakeholders to participate, which brought the total number of stakeholders to 730.

The stakeholders were provided with information about the research and invited to take part in each stage of the study via email (unless they previously withdrew their consent).

Overall, 289 stakeholders participated in the study. Of these 289 stakeholders, 220 participated in Stage 1 of the Delphi panel, 109 participated in Stage 2 of the Delphi panel, 79 attended the first remote workshop, and 81 attended the second remote workshop.

Stakeholders belonged to various groups, which allowed us to obtain informed opinions from a range of experts:

- PMD manufacturers
- PMD ride sharing schemes
- PMD retailers
- Consumer groups (including vulnerable road users, people with disabilities etc.)
- Trade bodies (such as Light Electric Vehicles Association [LEVA], Confederation of the European Bicycle Industry [CONEBI], European Cycling Federation [ECF])

9.1.4. Procedure

9.1.4.1. Stage 1 of the Delphi panel

This online survey was hosted on SmartSurvey and consisted of mainly open-ended questions. During this survey, stakeholders were asked to complete a consent form and list what they thought would be the best regulatory measures for the safe use of PMDs on public roads. Stakeholders were asked to list suggestions for each of the following seven categories of measures:

1. Measures related to user restrictions (regulations regarding who is allowed to use PMDs in public places [e.g. age limits, licensing, whether they have insurance etc.])

2. Measures related to user behaviour (restrictions that should be placed on people while they are using PMDs in public places [e.g. intoxication, the use of helmets and other PPE, the use of mobile phones etc.])

3. Measures related to traffic rules (the types of road, cycle path or footway that PMDs are allowed to be used on and the road regulations that should apply to them [e.g. speed limits, right of way, stop signs etc.])

4. Measures related to technical compliance (the way in which PMDs are assessed to ensure that they comply with any technical regulations [e.g. Type-approval, self-certification by manufacturers, periodic technical inspections, market surveillance etc.])

5. Measures related to the categorisation of PMDs (the way in which PMDs are separated for regulatory purposes from other types of vehicle [e.g. motorcycles or cars], and whether there is a requirement to separate PMDs into different categories [e.g. by configuration – number of wheels etc., by power, by mass, by speed, by kinetic energy etc.])

6. Measures related to vehicle performance (the way in which the whole vehicle behaves [e.g. stopping distances, acceleration, maximum speed, maximum allowable mass, structural integrity, crashworthiness, vehicle dimensions etc.])

7. Measures related to vehicle systems (the features of PMDs that should be required for them to be used safely in public places and the required performance of those features [e.g. braking, lighting, audible warning devices, electrical safety, mirrors etc.])

The number of suggestions each stakeholder provided for each category was limited to five, with the aim of focusing stakeholders' efforts on providing what they believed to be the best suggestions.

Once the survey had been closed, all suggestions provided for each category of measures were collated and organised, which involved:

- Removing duplicate suggestions
- Removing suggestions outside of the study's scope (such as suggestions related only to PMD types that are excluded from the study)
- Rewording or rephrasing suggestions to improve clarity
- Grouping suggestions into subcategories within the seven main categories of measures

9.1.4.2. Stage 2 of the Delphi panel

The collated suggested measures from Stage 1 of the Delphi panel informed the content of a second survey. During this survey, stakeholders were asked to rate the potential regulatory measures (within their respective categories) in terms of:

a. Practicality (for the users, manufacturers, and enforcement bodies)

b. Economic effect (including implementation costs and market growth)

c. Effectiveness at minimising the likelihood of injury due to the use of PMDs

The survey was hosted on SmartSurvey and consisted mainly of five-point Likert-type scales (with responses ranging from 'Very impractical' to 'Very practical, 'Very detrimental' to 'Very beneficial' [for the economy], and 'Very ineffective' to 'Very effective'). 'Don't know/not applicable' was also included as an option for respondents.

Once the survey had been closed, each response was assigned a score from one to five (e.g. a rating of 'Very detrimental' was assigned a score of one and a rating of 'Very beneficial' was assigned a score of five). 'Don't know/not applicable' responses were excluded from analysis. The mode average scores for each suggestion were then calculated to provide the following:

- An average practicality score (a combined average of practicality scores in relation to users, manufacturers, and enforcement bodies)
- An average economic effect score
- An average effectiveness score

As well as rating the suggested measures, participants were also asked several additional questions about:

- Whether they thought age restrictions for using PMDs should be mandated, and what they thought the age limits for using PMDs should be
- Whether they though adult supervision for children riding PMDs should be mandated, and at what age they thought children should be allowed to use PMDs without adult supervision
- Whether they thought a maximum speed restriction/motor power limit/unladen mass limit/laden mass limit for all PMDs should be set and mandated, and what they though the maximum speed restriction/motor power limit/unladen mass limit/laden mass limit for all PMDs should be

Once the survey had been closed, the mode averages were calculated for each of these additional questions.

9.1.4.3. Remote stakeholder workshops

To help ensure stakeholders only participated in discussions that they felt they could contribute to, two workshops were held, each with different focuses:

- The first workshop focused on measures related to user restrictions, user behaviour and traffic rules
- The second workshop focused on measures related to technical compliance, categorisation of PMDs, vehicle performance, and vehicle systems

Prior to the workshops, potential participants were asked to complete an online survey to inform us which of the workshops they would like to attend and to provide their consent.

The collated suggestions from Stage 1 of the Delphi panel informed discussion during the workshops. The aim of the workshops was to identify any evidence that supported or opposed the potential regulatory measures, and to add nuance to the quantitative results of Stage 2 of the Delphi panel.

Each workshop lasted approximately three hours and was structured as follows:

1. Welcome, introductions, and a brief summary of the research

2. Presentation and descriptions of the potential regulatory measures within their respective categories

3. Group discussion of any supporting or opposing evidence (either anecdotal or empirical) for each measure. For example, participants were asked if they knew of any evidence pertaining to:

    a. How easy or difficult implementing these types of measures has been in the past

    b. How much these types of measures have costed to implement in the past

    c. How effective or ineffective these types of measures have been at reducing collisions or injuries in the past

4. Conclusions and ‘any other business’ (including offering stakeholders the opportunity to ask questions or make any final comments about the measures or the research)

PowerPoint presentation slides and a semi-structured topic guide were used to ensure a consistent facilitation approach and to ensure the aims of the research were achieved. The workshops were held remotely via Zoom (a video conferencing tool), which allowed the researchers to share the presentation slides and record the workshops for data analysis purposes.

Audio recordings of the workshops and any files containing written comments from participants (e.g. from the chat function) were analysed using thematic analysis, which allowed for identification of patterns within the qualitative dataset.

9.2. Findings

9.2.1. Findings from the Delphi panel

Stakeholders provided a total of 4,348 submissions for the survey for Stage 1 of the Delphi panel. These submissions were collated and organised, resulting in 143 potential regulatory measures for the safe use of PMDs (shown in the tables in the following subsections), which were taken forward to Stage 2 of the Delphi panel.

The following tables show the average ratings (mode) from Stage 2 of the Delphi panel for each measure suggested by stakeholders, with a score of 1 representing the lowest average rating (i.e. very impractical, detrimental to the economy, or ineffective at reducing the likelihood of injury) and a score of 5 representing the highest average rating (i.e. very practical, beneficial to the economy, or effective at reducing the likelihood of injury).

The measures in the below tables have been colour-coded based on their average ratings:

- Measures in red were generally NOT rated as somewhat or very practical, beneficial to the economy, or effective at reducing the likelihood of injury (n=24)

- Measures in amber were generally rated as somewhat or very practical, beneficial to the economy, OR effective at reducing the likelihood of injury (n=67)

- Measures in green were generally rated as somewhat or very practical, beneficial to the economy, AND effective at reducing the likelihood of injury (n=52)

9.2.1.1. Measures related to user restrictions

Stakeholder opinions of the measures related to user restrictions were fairly mixed. There was a particular preference for implementing restrictions based on PMD type and uniformly across all countries (independent of national rules). There was some support for licensing and insurance from a safety perspective, but mandating either of these was seen as being largely impractical. Mandating age restrictions was seen as being more practical.

Table 14: Regulatory measures related to user restrictions suggested by stakeholders

Subcategory	Measure	Mode averages		
		Practicality	**Economic effect**	**Effectiveness at reducing injury**
Age restrictions	Mandate age restrictions	4	2	4
Licensing	Recommend basic training (voluntary)	3	4	4
	Mandate basic training	1	2	4
	Recommend licensing (voluntary)	1	2	3
	Mandate licensing	1	1	4
	Mandate moped licences for PMDs	1	1	4
	Prohibit riding by people who have been banned from using other types of vehicle	1	2	5
Insurance	Recommend insurance (voluntary)	3	4	3
	Mandate insurance	1	1	3
Other	Allow anyone to ride PMDs without restrictions	5	5	1
	Impose the same restrictions for all PMDs	1	5	3
	Impose user restrictions based on PMD type (e.g. based on speed, weight, power)	4	4	4
	Impose the same user restrictions across all countries	5	5	4
	Impose the same user restrictions depending on national rules	3	2	3
	Prohibit riding of PMDs by people who would be medically unfit to use other types of vehicle	2	2	4

9.2.1.2. Measures related to user behaviour

Stakeholder opinions of the measures related to user behaviour were largely very positive, particularly for measures related to intoxication and distracted driving. There was also support for recommending the use of personal protective equipment and helmets, although mandating either of these was seen as being impractical.

Table 15: Regulatory measures related to user behaviour suggested by stakeholders

Subcategory	Measure	Mode averages		
		Practicality	Economic effect	Effectiveness at reducing injury
Intoxication	Set intoxication limits	5	5	5
	Prohibit riding by people who are intoxicated	5	5	5
	Match intoxication restrictions for PMDs to intoxication restrictions for bicycles	5	5	5
	Match intoxication restrictions for PMDs to intoxication restrictions for other motorists	5	5	5
Distracted riding	Recommend handsfree mobile device use (voluntary)	4	4	4
	Prohibit use of handheld mobile devices except for navigation purposes	5	4	5
Personal protective equipment	Recommend wearing of personal protective equipment (voluntary)	4	4	4
	Mandate wearing of personal protective equipment	1	1	5
	Allow people to ride PMDs without motorcycle helmets	5	5	3
	Recommend wearing of helmets (voluntary)	5	4	4
	Mandate wearing of helmets	1	1	5
	Mandate wearing of bicycle helmets	1	2	5
	Match helmet regulations for PMDs to helmet regulations for bicycles	5	5	5
	Mandate wearing of protective padding	1	1	4
	Mandate wearing of high visibility clothing	1	1	5
Transporting passengers or goods	Prohibit the transportation of more weight or passengers than the PMD is designed to carry	4	2	5
	Prohibit transportation of unsecured goods	4	2	4
Other	Allow people to ride PMDs without behaviour restrictions	1	5	1
	Match user behaviour restrictions for PMDs to user behaviour restrictions for bicycles	5	5	4

9.2.1.3. Measures related to traffic rules

Stakeholder opinions of the measures related to traffic rules were fairly mixed. There was support for mandating specific speed limits, adherence to the highway code and rules applying to bicyclists, and requiring appropriate lighting. However, there was less support for restricting where PMDs could be ridden or parked.

Table 16: Regulatory measures related to traffic rules suggested by stakeholders

Subcategory	Measure	Mode averages		
		Practicality	Economic effect	Effectiveness at reducing injury
Permitted routes	Allow PMDs to be ridden anywhere	5	5	2
	Allow PMDs without handlebars (e.g. hoverboards) to be used in public places	5	5	3
	Prohibit PMDs from using pedestrian footways	2	2	4
	Prohibit PMDs from using bicycle lanes	1	1	1
	Prohibit PMDs from using the road	1	1	2
	Prohibit PMDs from using roads with speed limits that are incompatible with their use	3	2	5
	Prohibit PMDs from using rural roads	1	1	2
Manoeuvres	Allow PMD users to ride through red traffic lights after stopping	3	1	1
	Mandate stopping at stop signs	3	5	5
	Mandate signalling before making a turn	3	2	4
	Mandate compliance with one-way streets	3	4	4
Parking	Require PMDs to park in specific areas	1	2	3
	Prohibit PMDs from parking in areas where they would cause an obstruction	3	4	3
	Allow PMDs to park in areas that are prohibited for other vehicles	4	4	3
Other	Develop harmonised EU traffic rules for all PMDs	5	5	4
	Mandate user adherence to the highway code	5	4	4
	Require PMD users to follow the same rules as bicyclists	4	4	4
	Mandate specific speed limits for PMDs (on cycle paths, pedestrian footways and the road)	4	4	4
	Require PMDs to give way to pedestrians	3	5	4
	Require other road users to give way to PMDs	3	4	4
	Prohibit PMDs from being used at night	1	1	4
	Mandate vehicle registration	1	1	3
	Mandate the fitment of registration plates	1	1	3
	Require all PMDs to be appropriately lit	5	4	5

9.2.1.4. Measures related to technical compliance

Stakeholder opinions of the measures related to user restrictions were fairly positive. There was general agreement that there should be a level of regulation in this area applied to all producers of PMDs, regardless of their size. There was particular support for developing a harmonised safety standard across the EU, containing minimum technical standards that all PMDs must comply with. However, there was less support for requiring all vehicles to undergo type-approval, periodic technical inspections and mandating the keeping of maintenance logs.

Table 17: Regulatory measures related to technical compliance suggested by stakeholders

Subcategory	Measure	Mode averages		
		Practicality	Economic effect	Effectiveness at reducing injury
Approval approach	Develop a harmonised European safety standard for all PMDs	5	5	5
	Require PMDs to comply with minimum technical standards	5	4	5
	Require all PMDs to comply with Regulation (EU) No 168/2013	1	1	4
	Exempt small producers from technical regulations	1	2	2
	Create a dedicated type-approval system for PMDs	4	4	4
	Require all PMDs to undergo type-approval	1	1	4
	Require PMDs in certain categories to undergo type-approval	4	2	4
	Require all PMDs to be self-certified by their manufacturer	4	4	4
	Require PMDs in certain categories to be self-certified by their manufacturer	4	4	4
	Require PMDs to pass mandatory safety tests	4	4	4
	Require all PMDs to be assessed by an independent technical service	3	2	4
	Require PMDs in certain categories to be assessed by an independent technical service	4	2	4
Regulations	Require all manufacturers to use a recognised quality management process (e.g. ISO9001)	3	1	4
	Require manufacturers to provide instruction manuals that define maintenance and service information	5	4	5
	Require manufacturers to analyse and publish the details of technical failures with their products	3	2	4
Enforcement of technical regulations	Require market surveillance to ensure conformity of production	3	4	4
	Prohibit the sale of tampering solutions	5	5	5
	Enforce anti-tampering measures	5	4	5
Periodic Technical Inspection (PTI)	Require that all PMDs be maintained in a roadworthy condition at all times	3	4	4
	Mandate periodic technical inspection for all PMDs	1	1	4
	Mandate keeping a maintenance log for each PMD	1	1	3

9.2.1.5. Measures related to categorisation of PMDs

Stakeholder opinions of the measures related to how PMDs should be categorised were fairly mixed. There was particular support for categorising PMDs based on their maximum speed and certain other physical properties, such as maximum laden mass, whether the user is required to sit or stand and whether or not the PMD is self-balancing. However, there was less support for categorising based on vehicle dimensions, maximum unladen mass, the number of wheels, power ratios or the intended use of the vehicle.

Table 18: Regulatory measures related to categorisation of PMDs suggested by stakeholders

Subcategory	Measure	Mode averages		
		Practicality	Economic effect	Effectiveness at reducing injury
Physical properties	Categorise based on vehicle dimensions	2	2	3
	Categorise based on maximum unladen mass	1	1	3
	Categorise based on maximum laden mass	4	4	4
	Categorise based on maximum number of occupants	1	4	4
	Separate PMDs which require users to sit from PMDs which require users to stand	5	4	4
	Categorise based on the number of wheels	1	1	3
	Separate single-wheeled PMDs from multi-wheeled PMDs	4	4	4
	Separate single track PMDs (e.g. e-scooters) from multi track PMDs (e.g. hover-boards)	1	1	4
	Categorise based on steering method	1	1	4
	Separate self-balancing PMDs from non-self-balancing PMDs	5	4	4
Power assistance	Separate PMDs that are driven by internal combustion engines from PMDs that are driven by electric motors	5	4	3
	Separate PMDs which are fully self-propelled from PMDs which are user-assisted	5	4	3
	Categorise power-assisted PMDs based on human-to-motor power ratio	3	1	3
Vehicle performance	Categorise based on maximum power	1	4	4
	Separate PMDs with a maximum power of up to 250W from other PMDs	1	4	4
	Separate PMDs with a maximum power of up to 500W from other PMDs	1	4	4
	Separate PMDs with a maximum power of up to 1,000W from other PMDs	4	4	4
	Categorise based on power-to-weight ratio	2	2	4
	Categorise based on maximum speed	5	4	5
	Categorise based on maximum speed without human effort	4	4	4
	Separate PMDs with a maximum speed of 6kmh from other PMDs	5	4	4
	Separate PMDs with a maximum speed of 25kmh from other PMDs	5	4	4
	Separate PMDs with a maximum speed of 32kmh from other PMDs	4	4	4
	Separate PMDs with a maximum speed of 45kmh from other PMDs	4	4	4
	Categorise based on kinetic energy (mass and speed)	1	2	4
Other	Develop different categories for different PMD types	5	4	4
	Minimise the number of categories to keep the system simple	5	5	3
	Separate PMDs which carry cargo from PMDs which carry passengers	1	4	4
	Separate PMDs intended for personal use from PMDs intended for commercial use	1	1	3

9.2.1.6. Measures related to vehicle performance

Stakeholder opinions of the measures related to vehicle performance were fairly positive. There was general agreement that there should be some restrictions on vehicle performance, with a particular preference for maximum speed limits, and minimum requirements for structural integrity and vehicle durability.

Table 19: Regulatory measures related to vehicle performance suggested by stakeholders

Subcategory	Measure	Mode averages		
		Practicality	Economic effect	Effectiveness at reducing injury
Power	Set maximum power limits	4	2	5
Speed	Set maximum speed limits	5	4	5
Mass	Set maximum laden vehicle mass limits	4	2	4
	Set maximum unladen vehicle mass limits	4	2	4
Structural integrity	Set minimum structural integrity requirements	4	4	5
	Set minimum vehicle durability requirements	4	4	5
Stability/ controllability	Set minimum stability requirements	4	2	5
	Set minimum controllability requirements	4	2	5
	Set minimum steering performance requirements	4	2	4
Other	Allow PMDs to be used without any restrictions on their performance	1	4	1
	Set maximum acceleration limits	4	2	4
	Set minimum braking performance requirements	5	4	5
	Set maximum vehicle dimension limits	4	2	4
	Develop safety standards based on kinetic energy levels	3	2	3

9.2.1.7. Measures related to vehicle systems

Stakeholder opinions of the measures related to vehicle systems were fairly positive, with a couple of exceptions. There was general agreement that there should be regulations in place for at least some systems, with a particular preference for mandating speedometers and audible warning devices, and for mandating minimum standards for braking and lighting systems, wheels and tyres. There was less support for mandating fitment of noise emitters, mirrors or stands, and for mandating a maximum number of wheels.

Table 20: Regulatory measures related to vehicle systems suggested by stakeholders

Subcategory	Measure	Mode averages		
		Practicality	Economic effect	Effectiveness at reducing injury
Minimum equipment	Mandate the fitment of speedometers	5	5	5
	Mandate systems which prevent unauthorised use of PMDs	4	4	4
	Mandate the fitment of audible warning devices (bells/horns)	5	4	4
	Mandate the fitment of constant noise emitters	1	2	3
	Mandate the fitment of mirrors	1	1	4
	Mandate the fitment of stands	3	1	3
Braking systems	Develop requirements for braking system capacity based on vehicle performance	5	4	5
	Mandate the fitment of mechanical brakes	5	4	5
	Mandate the fitment of at least two independent braking systems to provide redundancy	5	4	5
Wheels/ tyres	Mandate minimum standards for wheels and tyres	4	4	5
	Mandate a maximum number of wheels	1	1	3
Electrical safety/ standards	Mandate compliance with European electrical safety regulations	3	4	5
	Develop battery and charger safety requirements	5	4	5
	Develop electromagnetic compatibility requirements	3	5	5
Lighting	Mandate minimum lighting standards	5	4	5
	Mandate the fitment of brake lights	5	2	5
	Mandate the fitment of indicators	3	1	4
	Mandate the fitment of reflectors	5	4	5
Other	Mandate the fitment of systems which remotely stop all shared PMDs	1	2	3
	Develop a standard for towing arrangements	3	1	3

Analysis of responses to the additional survey questions during Stage 2 of the Delphi panel showed that, out of 109 survey respondents:

- 36% (n=39) thought that age restrictions for using PMDs should be mandated; on average, these respondents suggested the minimum age for PMD use should be 14 years old
- 28% (n=31) thought that adult supervision for children riding PMDs should be mandated; on average, these respondents suggested the minimum age for PMD use without adult supervision should be 16 years old
- 71% (n=77) thought that a maximum speed restriction for all PMDs should be set and mandated; on average, these respondents suggested the maximum speed restriction should be 25km/h
- 28% (n=30) thought that a maximum motor power limit for all PMDs should be set and mandated; on average, these respondents suggested the maximum motor power limit should be 1kW
- 20% (n=22) thought that a maximum unladen mass limit for all PMDs should be set and mandated; on average, these respondents suggested the maximum unladen mass limit should be 30kg
- 57% (n=62) thought that a maximum laden mass limit for all PMDs should be set and mandated; on average, these respondents suggested the maximum laden mass limit should be 200kg

9.2.2. Findings from the remote stakeholder workshops

This section details the feedback obtained from stakeholders during the workshops on the potential regulatory measures which were discussed, along with any anecdotal or empirical evidence they provided to support or oppose the measures.

A general pattern observed among stakeholders was that they tended to supported customs for regulating PMDs that had developed over time, rather than question the background of these customs or use evidence to determine whether these customs should still be applied. A small number of participants recognised that some regulations were purely historic, such as motor power limits and speed limits for PMDs.

Another general observation was that stakeholders tended to support the idea of having some uniformity of regulatory measures across countries (although national infrastructure should inform some regulatory measures). However, they opposed the idea of the same regulations being applied to various PMD types, and suggested that application of regulations should instead be based on the level of risk associated with each PMD type.

Additionally, many stakeholders held the opinion that infrastructure should be improved and consideration for PMDs should be made when improving infrastructure (e.g. lowering speed limits for other vehicles in cities to accommodate for PMDs), as implementing regulations with poor infrastructure would be ineffective. Stakeholders also highlighted that regulating PMDs to suit existing (improved) infrastructure would be easier and more cost-effective than changing infrastructure to suit PMD use.

9.2.2.1. Measures related to user restrictions, user behaviour and traffic rules

Generally, stakeholders supported matching restrictions for PMD use to existing user restrictions for bicycle use (including restrictions on how PMDs should be used and where they should be used). This was especially true for EPACs and other PMDs with a maximum speed of 25km/h. There was general consensus that there should be more flexibility regarding where PMD use is permitted. For example, permitting PMD use where bicycle use is usually permitted (such as bicycle lanes and roads) and requiring PMD users to follow the same rules as bicyclists. Some stakeholders explained that restrictions for PMD use and bicycle use should be similar because PMDs pose similar risks to those of bicycles.

Several stakeholders also felt that local authorities should be given responsibility for deciding where PMDs can be ridden (to ensure permitted routes can be customised to suit infrastructure). Additionally, stakeholders suggested that permitted routes should be based on user behaviour, rather than PMD features; in other words, the potential maximum speed of PMDs is not as important as the behaviour of PMD users (which is already the norm for other forms of transport, such as cars). For example, PMD users should be allowed to use bicycle lanes if they adhere to bicycle lane rules, to use footways (especially for deliveries, parking, and access to public transport) if they adhere to walking-pace speed limits (e.g. 5km/h), or to use roads if they adhere to the speed limits of each road. This suggestion is supported by Aarts and van Schagen (2006) and Kloeden, McLean, Moore and Ponte (1997), who propose that all vehicles should travel at the same speed on the same road to reduce the risk of collisions. Correspondingly, some stakeholders held the opinion that PMDs should not be ridden on roads if their maximum speed is lower than the road's speed limit, as travelling at a slower speed than the rest of the traffic may be hazardous.

There was general consensus among stakeholders that intoxication limits for users should be set, drink-riding or drug-riding PMDs should be prohibited, handheld mobile phone use when riding PMDs should be prohibited, and transporting passengers should be prohibited on PMDs which are not designed to carry passengers. In addition, stakeholders welcomed the idea of recommending the wearing of helmets and personal protective equipment (PPE; such as knee pads, elbow pads or high visibility clothing). However, *mandating* the wearing of helmets and PPE, as well as mandating licensing, insurance, user registration and vehicle registration were not viewed as favourably. Some stakeholders explained that, although such mandatory measures may reduce the likelihood of injury associated with using PMDs, they could be difficult to enforce and could make using PMDs too onerous for users. Ultimately, this could lead to reduced uptake of PMDs, which would be detrimental to the PMD market and could encourage members of public to adopt other, less environmentally-friendly forms of transport (e.g. cars). Reduced uptake of PMDs could also reduce the 'Safety in Numbers' effect, whereby PMD users are less likely to be injured where PMD use is more prevalent (Fishman & Schepers, 2018). Some stakeholders had also observed that PMD users were becoming increasingly willing to wear helmets voluntarily, so mandating the wearing of helmets may not be necessary. In addition, some stakeholders noted that insurance and licensing would be particularly troublesome due to PMDs not yet being fully regulated and due to the age of PMD users (i.e. with most EU countries only permitting licences for users that are at least 16 or 18 years old); these difficulties would make mandatory insurance problematic for PMD users.

Several stakeholders suggested that user restrictions should differ between PMD types. For example, age limits for riding slower PMDs (e.g. those with a maximum speed of 25km/h) should be lower than with faster PMDs (e.g. those which travel faster than 25km/h). However, some stakeholders suggested that implementing age restrictions does not improve safety. Furthermore, several stakeholders thought that imposing age restrictions or requiring adult supervision for children under a certain age may hinder PMD use, which particularly applies to children who would rely on using PMDs to attend school.

9.2.2.2. Measures related to categorisation of PMDs

While some stakeholders suggested that existing segmentations based on vehicle capability are out-of-date because they are not based on the current capabilities of PMDs, others suggested there are no safety issues with the existing categorisation.

Stakeholders were generally keen on categorising PMDs according to their speed (particularly separating PMDs with a maximum speed of 25km/h to those with higher maximum speeds, as this was seen by some as the maximum speed at which most people can run without assistance), power, or laden mass because these characteristics were considered good indicators of the level of risk posed by each type of PMD. Conversely, stakeholders did not generally support the idea of categorising PMDs based on their physical characteristics (e.g. dimensions, unladen mass, or number of wheels) or whether they are used for personal or commercial purposes, as these were considered poor indicators of the risk levels posed by each type of PMD.

Views on whether PMDs should be categorised according to their kinetic energy levels or acceleration were mixed, with some stakeholders supporting these ideas and others indicating that speed is more important.

9.2.2.3. Measures related to technical compliance, vehicle performance and vehicle systems

Although some stakeholders thought that there are no safety issues with existing regulations for PMDs, others disagreed and thought regulations should be revised (especially for e-scooters because they are not currently regulated, as supported by Iftakhar and Iftakhar's 'Scooter Safety Manifesto', 2020). Additionally, one stakeholder provided anecdotal evidence that market surveillance does not currently work to enforce regulations.

Stakeholders were generally supportive of mandating minimum safety standards, safety testing, and self-certification by manufacturers for PMDs. However, they indicated that manufacturers and approvers have a lack of practice with regulating technical approval of PMDs. Opinions on whether small producers should be exempt from having to adhere to technical regulations were mixed; although some stakeholders disagreed with this exemption, others were concerned that small producers were unaccustomed to, and could struggle to adhere to, strict regulations (therefore risking going out of business). In addition, stakeholders revealed overall pressure to minimise the number of technical regulations and avoid unnecessary complexity to prevent the obstruction of PMD development and uptake.

Stakeholders were also generally supportive of type-approval, but suggested that the national type-approvals that are currently available are impractical and onerous (especially for EPACs and cargo bikes). Furthermore, many stakeholders suggested type-approval for EPACs would not be very helpful. As EPACs were generally seen as posing the same risks as bicycles, many stakeholders were of the opinion that type-approval would not be worth the perceived administrative burdens associated with the type-approval process. Regarding cargo bikes, some stakeholders suggested that current testing and testing facilities are inadequate, which makes type-approval more difficult. In support of this, one stakeholder cited evidence from a survey that 18% of cargo bike manufacturers had started the type-approval process, but only one company completed the process and reached the market.

In terms of setting safety requirements for PMDs, stakeholders generally agreed that setting maximum speed limits, and setting requirements for battery and charger safety, lighting, structural integrity, and vehicle durability were important. Stakeholders also generally agreed that setting requirements for wheels and tyres was important, but indicated that there is a distinct lack of data on tyres that can be used to inform the design of tyres for PMDs. Stakeholders suggested that larger wheels improved stability of PMDs. Although most stakeholders were opposed to developing safety standards based on kinetic energy and stated that there is more evidence about the relationship between speed and collision risk than between kinetic energy and collision risk, some claimed that higher kinetic energy levels are associated with greater collision risk.

Requirements for braking systems were also important to stakeholders, with many in favour of setting minimum braking performance requirements, and mandating the fitment of mechanical brakes or at least two independent braking systems. However, thoughts on requirements for acceleration limits were mixed; though some stakeholders believed acceleration should be limited (rather than motor power), others suggested that quick acceleration makes using PMDs among other traffic safer and helps with balancing (e.g. when using a unicycle) or that setting motor power limits is more important than setting acceleration limits. However, several participants highlighted that limiting motor power may actually cause some safety issues with PMDs not being able to keep up with other traffic when travelling uphill, and may also hinder product development.

Setting requirements for the weight or mass of PMDs was also important to some stakeholders, whereas other PMD characteristics (e.g. braking performance and structural requirements) were more important to other stakeholders. Although results from the Delphi panel showed that many participants agreed on a 200kg maximum laden mass for PMDs in general, workshop participants suggested that a greater laden mass limit for cargo bikes should be permitted (e.g. 600kg). Some stakeholders suggested that wider PMDs have a greater chance of being involved in collisions, whereas others suggested that wider PMDs have greater stability (especially cargo bikes).

Stakeholders were also in favour of requiring PMDs to be fitted with speedometers, audible warning devices (e.g. bells or horns), and reflectors. Conversely, mandating the fitment of constant noise emitters, stands, a certain number of wheels, towing apparatus, and systems which remotely stop all shared PMDs were not popular. More generally, a small number of stakeholders suggested that mobile parts on PMDs and liquids within them should be kept to a minimum to improve safety.

Additionally, stakeholders were in favour of requiring PMDs to be fitted with systems which prevent unauthorised use. Instead of engraving a Vehicle Identification Number (VIN) on the body of each PMD for anti-theft purposes or relying on the police to deal with cases of stolen PMDs (which they do not always have the resources to do), some stakeholders proposed systems whereby PMDs are digitally registered and can be digitally disabled, which they expected would be a more effective anti-theft approach. However, there were some concerns that such systems may be detrimental to the second-hand PMD market.

Enforcement of anti-tampering measures and banning the sale of tampering solutions was also viewed positively by stakeholders, particularly because tampering had become a widespread issue in some countries. However, one stakeholder suggested that even having three independent anti-tampering measures would not prevent tampering completely, and would increase the cost of manufacturing PMDs.

Overall, stakeholders were opposed to mandating the keeping of maintenance logs for each PMD. As periodic technical inspection (PTI) relies on keeping maintenance logs, it was also not viewed favourably. Some stakeholders explained that these measures may be too onerous for PMD users and therefore discourage PMD uptake. However, they felt that manufacturers should be required to provide instruction manuals for users that include maintenance and service information.

9.3. Conclusions

Outcomes of the Delphi panel generated a set of 52 potential regulatory measures that stakeholders generally regarded as practical, beneficial for the economy, and effective at reducing the likelihood of injury associated with using PMDs.

Overall, stakeholders suggested simplifying regulations to encourage PMD uptake and enhance market growth. However, stakeholders agreed that the same regulatory measures should not be applied to all PMDs, as different types of PMD pose differing levels of risk. For the same reason, applying the same regulatory measures for bicycles to EPACs and other PMDs with a maximum speed of 25km/h was also widely proposed.

Stakeholders also recommended that PMD users should be required to obey the rules of where the PMD is being ridden (e.g. adhering to the speed limits on roads or bicycle lanes). Where some user restrictions were popular (e.g. prohibiting intoxicated riding and handheld mobile phone use) as they were expected to improve safety, stakeholders opposed mandating other measures (e.g. mandating the wearing of helmets or other PPE, licensing or insurance) to avoid discouraging PMD uptake.

Stakeholders were keen to categorise PMDs based on the level of risk posed by each PMD type. Good indicators of risk were thought to be speed, power and laden mass, whereas physical characteristics (e.g. dimensions, unladen mass and number of wheels) and type of use (i.e. personal versus commercial) were viewed as poor indicators of risk.

Minimum safety standards, safety testing, self-certification and type-approval were generally supported by stakeholders. However, some implied that the current type-approval process needs to be reviewed, as it is impractical and type-approval is too difficult to obtain, which hampers the PMD market. Although PTI was unpopular among stakeholders, they felt that PMD manufacturers should be required to provide users with instruction manuals.

Stakeholders generally agreed that setting maximum speed limits, and setting requirements for braking performance, battery and charger safety, wheels and tyres, lighting, structural integrity, and vehicle durability were important. Requiring PMDs to be fitted with particular equipment (e.g. speedometers, audible warning devices and reflectors) was also supported, as was banning the sale of anti-tampering measures.

Although this section provides numerous suggestions from a variety of PMD experts, there was little empirical evidence supplied by stakeholders on which to base regulatory measures. This highlights the need for further research on the feasibility, cost-effectiveness, and ability to improve safety of the regulatory measures which were widely supported by the stakeholders.

10. COST-BENEFIT ANALYSIS OF REGULATORY OPTIONS

In order to assess the economic impact of the regulatory options proposed in Section 3 a cost-benefit model was produced and an analysis was conducted of the options that would have the greatest effect on the development of the PMD market, i.e. Option 1 – mandatory type approval for all PMDs and Option 5 – self certification for all PMDs under 1kW and 30km/h. We did not consider it feasible to conduct a cost-benefit analysis of Options 2, 3 or 4 since we did not have access to data of sufficient granularity to be able to produce a useful model.

This economic analysis considers the effect of regulation on the growth of the PMD market and the likely shift in the modes of transport chosen, which in turn would lead to changes in collisions and casualty levels since different modes of transport have different rates of injury. This analysis assumes the risk within each transport mode does not change as a result of this shift. In reality, the scale of the mode shift can influence casualty rates, for example if large numbers of people shift from cars to bicycles, overall safety is improved because there are fewer opportunities for the more dangerous car-bicycle collisions to occur. However, due to the uncertainty around potential changes, it appears reasonable to assume the casualty rates for each mode would remain constant.

It is apparent from some of the responses collected in our stakeholder engagement exercise (Section 9) and data from our market review (Section 6) suggested that the most important factor in the behaviour of the PMD market is the way in which the use of these vehicles is regulated. While technical regulations and the manner in which they are enforced has an important effect from the perspective of manufacturers, in that it adds additional and relatively costly tasks to their development process, the economic effect on the market of technical regulations appears to be minimal. One manufacturer of electrically assisted bicycles claimed that type approval added only around €8 to the purchase price of one of their L-category bicycles which have a purchase price of around €1,600.

In order to forecast the effect of either requiring new types of PMD to be type approved or allowing manufacturers and importers to self-certify their vehicles we have made the following assumptions:

- In the case of mandatory type-approval, the market will respond in the same way as it has to vehicles in the L1e-B sub-category, i.e. a very significant reduction in the size of the market due to the additional barriers to ownership compared to bicycles.

- In the case of self-certification, the market will respond in the same as it has to EPACs, i.e. a rapid increase in uptake driven by low regulatory barriers to ownership and more attractive functionality.

- Any performance differences, for example with top speed and other aspects, between type-approved and self-certified PMDs would be insignificant and would thus not influence the behaviour of the market.

- There will be no significant difference in the rate or severity of collisions between type-approval and self-certification approaches.

10.1. Proposed regulatory option

In Section 3 we proposed a series of possible regulatory options for PMDs in the EU. Of these options, Option 1 would see all PMDs brought within the scope of Regulation (EU) No 168/2013, and consequently subject to mandatory type approval, but more importantly treated as L-category vehicles for the purposes of user regulations. While some member states have applied a slightly relaxed set of user regulations to cycles designed to pedal in

L1e-A and L1e-B, the inclusion of PMDs in the L-category would by default require their users to comply with the regulations applied to mopeds and other L-category vehicles unless a particular member state chose to apply a more relaxed set of regulations to them. In any case, it seems likely that inclusion in the L-category would require users to hold a suitable driving licence, wear a helmet and hold insurance.

In Option 5 we proposed a scheme of technical regulations that would exclude the majority of PMDs from the scope of Regulation (EU) No 168/2013 and thus the L-category. This solution is analogous to the regulations that are currently applied to EPACs across the EU, although it differs in that our proposal would create a new route to approval outside of the Machinery Directive. Crucially, for the purposes of user regulations, this would place PMDs on the same footing as EPACs and thus by extension pedal cycles. With this status user regulations would default to the same minimally restrictive condition applied to pedal cycles in all Member States, unless individual Member States chose to impose any additional regulations on them. In any case there would be no automatic requirement for users to hold a driving licence, wear a helmet or hold insurance.

These regulatory options can be broadly described as *Mandatory Type-approval* and *Self-certification.* We have sought to model the economic and safety effects of these two options over a ten-year period. We have taken the historical examples available from the behaviour of the market for electrically assisted bicycles, which conveniently have examples of both *Mandatory Type-approval* in the form of cycles designed to pedal in L1e-A and L1e-B and *Self-certification* in the form of EPACs. These examples are especially appropriate for our purposes since the basic design of all the machines concerned is identical. Viewed in more detail, parallels can be drawn between EPACs and cycles designed to pedal in L1e-A, which importantly have the same 25km/h maximum assistance speed limit. It is evident from the market performance of these two groups of vehicle that users have a very strong preference for EPACs over L1e-As and that the higher motor power allowed in L1e-A is not a sufficient inducement for users to choose them over the less tightly regulated EPACs. This has effectively completely stiffled the development of a market for cycles designed to pedal L1e-A. In comparing EPACs to cycles designed to pedal in L1e-B it is important to note that L1e-Bs have a 45km/h maximum assistance speed limit. Unlike L1e-As this higher speed limit has allowed cycles designed to pedal in L1e-B to develop a market, but it remains approximately 1% of that for EPACs. For the purposes of our model we have assumed that the market would respond in the same way as it has to the regulations applied to these groups of electrically assisted bicycle and that the primary effect of *Mandatory Type-approval* would be a significant reduction in market growth.

In order to understand the costs and benefits, it is important to make clear what the impact of regulation would be in economic terms. We have chosen here to model two potential future scenarios:

- Mandatory type approval - in which all PMDs become subject to type-approval under Regulation (EU) No 168/2013. This is Option 1 proposed in Section 3.1.1

- Self-certification – in which all PMDs under 1,000W and 25km/h would be excluded from type approval and subject to road circulation regulations similar to those for bicycles. This is Option 5 proposed in Section 3.1.5

The costs and benefits of these options are measured in terms of:

1) the impact on road collisions, and;

2) the impact on production costs.

The calculations rely on databases including the European Union's Community Road Accident Database (CARE) and studies conducted by such bodies as the International

Transport Forum on how road users might react to the growing popularity and availability of PMDs.

In Section 8.2 we presented the available data for the cycles designed to pedal in L1e-B market, which show that the size of this market is approximately 1% of that for EPACs. In order to forecast the likely sales trajectory of EPACs, and cycles designed to pedal in L1e-B, the annual sales growth of EPACs for the last 4 available years are averaged to 26%, with the figures for L1e-Bs being scaled accordingly. It may be reasonable to see growth continuing at this rate for the next decade, however for the purposes of this Cost-Benefit Analysis we have taken a levelling-off approach to reflect the potential course that PMDs will enter the maturity phase in the product lifecycle.

Over the 10-year evaluation period, it is expected that PMD circulation would continue to grow, but the rate of growth is gradually reduced to reflect a market that is maturing, and by 2030 saturating. Having considered a 2021 start of the proposed changes, the evaluation period was set to extend from 2021 to 2030 inclusive. The slower growth is given by a factor of 1/1.153 attached to each previous year's rate to arrive at the level predicted in Section 8.2 by 2030. Growth for these e-bike categories is then projected for 10 years as displayed in Table 21:

Table 21: Projected e-bike sales growth in the EU

Category	2021	2022	2023	2024	2025	2026	2027	2028	2029	2030
EPACs (million)	5.4	6.8	8.3	9.9	11.5	13.2	14.8	16.5	18.0	18.0
L1e-B (000s)	53.7	67.5	82.6	98.5	115.1	131.8	148.5	164.7	180.4	180.4

10.2. Evaluation period

To model the costs and benefits of the proposed measures fully, it was necessary to set an evaluation window which allows the market and road users sufficient time to adapt to the new regulatory and road circulation regimes. This also lets the PMDs add to the mode choice of road users. The latter mode shift is of great importance in understanding how more or less likely someone would get injured or killed on the road given the changes. The Cohesion Fund for instance laid guidance that technical installation proposals should have an evaluation period of 10-15 years (Florio & Vignetti, 2005). Given the continuous growth of the PMDs market including EPACs and e-scooters, it appears prudent to adhere analysis to the lower end of the suggested window.

10.3. Inflation adjustment

To adjust for the increases in the general price level between 2016 and 2021, actual and forecast inflation rates have been applied. This ensures past and current values are compared like-with-like. The inflation rate used is the year-on-year percentage change of the Harmonised Index of Consumer Prices (HCPI). Historic data have been published by Eurostat and forecasts by the European Central Bank. Table 22 below shows the inflation rates applied in the present study.

Table 22: Year-on-year inflation rates applied in the study

Year	Inflation rate (HCPI)	Type	Source
2017	1.54%	Actual	Eurostat
2018	1.75%	Actual	Eurostat
2019	1.20%	Actual	Eurostat
2020	0.30%	Actual	Eurostat
2021	1.10%	Forecast	European Central Bank

10.4. Costs of road casualties

The importance of road safety guides the decisions of policymakers and that importance is quantified within the Handbook of External Costs of Transport (van Essen et al., 2019). The estimated economic costs, as discussed in Section 7, consider the human, medical and administrative costs as well as property and production losses. Apart from the human cost component, the various elements comply with the European Commission-funded SafetyCube (Safety Causation, Benefits and Efficiency) project (Wijnen et al., 2017). The human cost component is valued base on the Value of Statistical Life based on estimations by the Organisation for Economic Co-operation and Development (OECD, 2012). The aggregate costs of collision to the EU are averaged across the 28 member states of the EU in 2016 and broken down into costs of fatalities, serious injuries and minor injuries.

To adjust for the increases in the general price level between 2016 and 2021, actual and forecast inflation rates are applied to the aggregate costs. This study recognises that there is some disparity in collision costs among EU member states. Generally speaking, countries with higher GDP have higher values of statistical life (VSL), e.g. Austria valued a life at double the monetary figure Bulgaria placed in 2016. The methodology behind the valuation is not the focus in the present study, which takes the average of the EU28. They are then uplifted according the HCPI indices above to reflect 2021 prices. Table 23 was constructed using these HCPI data to calculate the cost of casualty in 2021 prices.

Table 23: Cost per casualty by severity

Casualty type	2016 prices	2021 prices
Fatality	€3,273,909	€3,471,129
Serious Injury	€498,591	€528,626
Minor injury	€38,514	€40,834

10.5. Historic road casualty data

Casualty trends are projected separately, firstly for all transport modes except PMDs, and then solely for PMDs. To estimate the baseline for the first group of modes for the evaluation period of 2021-2030, we first take the historic fatality and injury data available from Europe’s Community Road Accident Database (CARE). The database records road collisions that resulted in death or injury but not damage-only collisions. The series of several countries started back in 1991 but in order to cover a comprehensive set of EU member states and transport modes the analysis included data from 2016 to 2018 inclusive. Data for 25 EU member states[18] are available for this period and because the data for 2019 appear to contain some errors, subsequent analysis excludes that year’s data altogether.

The CARE database returns various transport modes and this study is interested in ‘bus or coach’ (which we refer to as bus from here on), ‘car or taxi’ (which we refer to as car from here on), ‘pedestrian’ and ‘moped’. We focus on these 4 categories because there is evidence through surveys that if PMDs are to become more accessible, they would attract users from these categories. These mode shifts are discussed in more detail in the following subsections.

For PMDs, there has not been a unified approach on how collision data are recorded across all Member States. Several Member States have developed their own methodologies in documenting device types, geographical location etc. In an attempt to obtain reasonably

[18] Austria, Belgium, Croatia, Cyprus, Czech, Denmark, Estonia, Finland, France, Germany, Greece, Hungary, Ireland, Italy, Latvia, Luxembourg, Malta, the Netherlands, Poland, Portugal, Romania, Slovakia, Slovenia, Spain and Sweden

representative EU estimates, historic German data for EPACs and cycles designed to pedal in L1e-B from 2014 to 2019 inclusive have been collected for this baselining exercise (Section 7.3). The data available for these two types have been used as proxies for type approved (cycles designed to pedal in L1e-B) and non-type approved (EPACs) PMDs.

In Section 6.1 we showed that Germany has 40% of the EPAC market in Europe. We have consequently scaled the German EPAC casualty figures to the whole of the EU using this market proportion as the multiplier. This assumes that the injury rate for the whole of the EU is the same as Germany. It is important to note that there are countries where road collision rates are generally higher or lower. That variance likely exists in e-bikes as well and this study bases the analysis on the best available data.

10.6. Baseline extrapolation within the evaluation period

Projecting into the 2021-2030 evaluation period, it is important that the trajectories reflect the past trends. These trends are different across the various transport modes. To apply a consistent method that extrapolates past data into the future, the Ordinary Least Squares (OLS) method has been utilised. This is a statistical regression technique for predicting unknown values from existing data. The objective of the method is to minimise the residual sum of squares (RSS) in a linear fashion. In this way, extreme, one-off values would have less influence than if the rate of casualty change was adopted. Figure 36 shows the forecasted series of fatalities as a baseline assuming no change to regulatory changes.

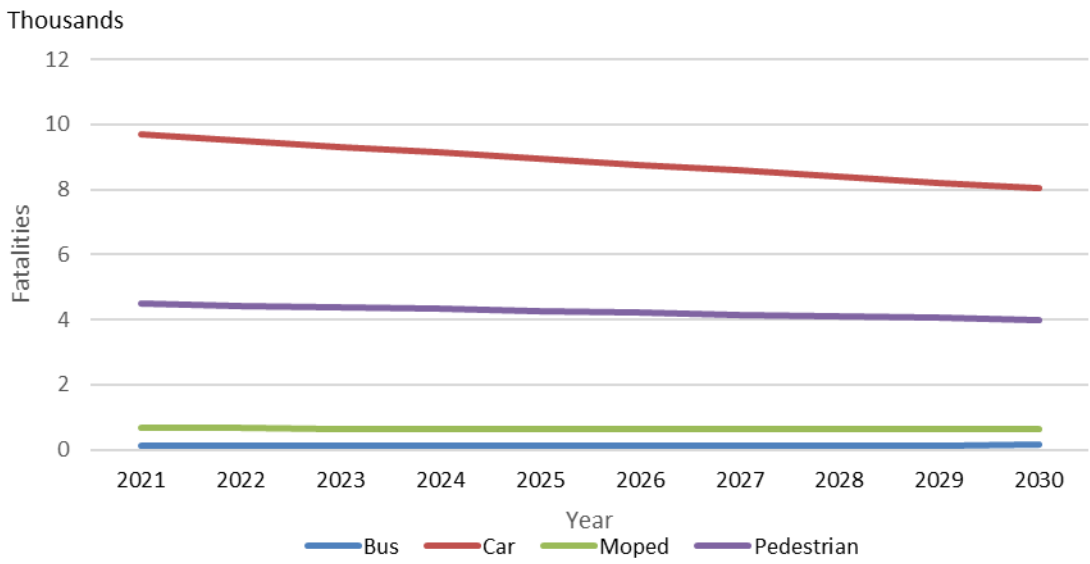

Figure 36: Projected fatalities in traditional transport modes across the EU

It can be seen that moped and bus fatalities are projected to remain relatively stable while car and pedestrian deaths would gradually decline. Car fatality is projected to drop from 9,691 in 2021 to 8,037 in 2030, and pedestrian fatality is forecast to fall from 4,484 in 2021 to 3,996 in 2030. Contrary to these modes, PMD casualty numbers are curtailed in a manner similar to the way in which PMD sales growth is. Furthermore, a plateauing factor of 95% is applied to the level of each type of projected casualty compared to the previous year. The combination of these curbing measures within the model reflects that as there are more PMDs on the roads, infrastructure is expected to improve. Figure 37 shows the PMD fatality project to plateau from 387 in 2021 and out to 725 in 2030.

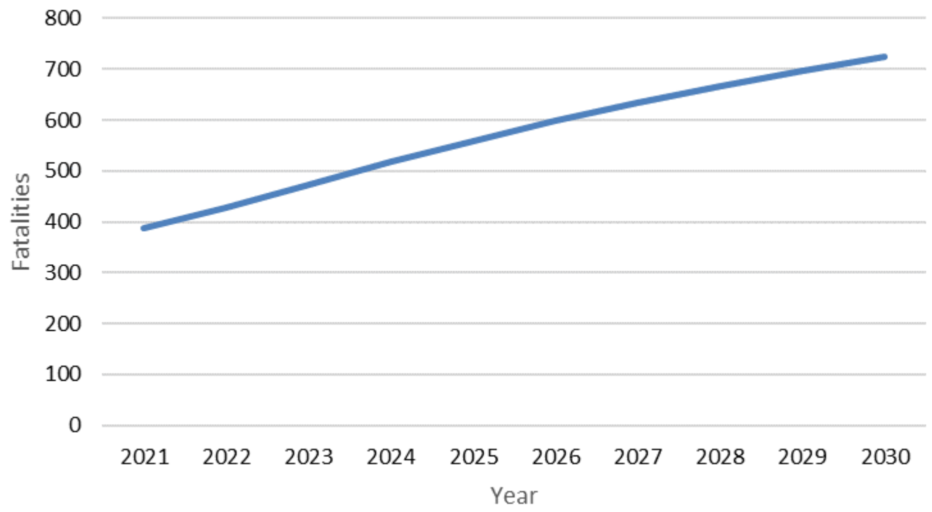

Figure 37: Projected fatalities from collisions involving PMDs

In the same ways, serious injuries and minor injuries have been projected for the 10-year evaluation period. The ratios of serious injuries and minor injuries to fatalities projected in 2021 are summarised in Table 24. In proportion terms, far more serious injuries per fatality are forecast for PMDs compared to other modes, but even more minor injuries per fatality are forecast for bus. This does not imply buses are not safe. In fact, buses are the safest of modes generally. But that means most of the casualties registered for buses relate to minor injuries, followed by PMDs then mopeds.

Table 24: Ratios of injury to fatality

	PMD	Car	Pedestrian	Bus	Moped
Serious Injury: Fatality	23.2	6.2	4.9	13.3	15.8
Minor Injury: Fatality	59.0	43.4	17.1	134.2	56.0

10.7. Projected casualties under policy proposals

The aggregate casualty cost difference between the two proposed policy options would represent a major part of the economic impact of the policy packages. To that end, it is necessary to understand the mode shifts that would follow from the growth of the PMD market. As it becomes easier to own and use PMDs, more road users may be tempted to give up their original transport mode, which includes walking, and use PMDs instead. In so doing, they would no longer be exposed to the casualty risk associated with the original modes and instead they would be exposed to the casualty risk associated with PMDs.

10.7.1. Estimates of mode shift from car, pedestrian and bus

The recent rapid growth in the PMD market, including e-bikes and e-scooters, raises the question of which other travel modes these devices are replacing. Zagorskas & Burinskiene, (2020) suggest that users are typically opting to utilise PMDs, instead of walking, cycling or driving, for journeys of less than 5km, in order to reach destinations such as public transport, leisure activities or supermarkets.

Research from FERSI (2020) suggests that across Europe, e-scooters mainly replace walking and public transport. This is supported by the ITF (2020), whose research indicated that the mode shift from car/taxi to standing e-scooters was considerably lower in major European cities compared with major cities in the United States and New Zealand, which likely reflects the differences in car usage in urban areas between these regions.

It is difficult to forecast how transport behaviour would shift against the backdrop of ongoing technological advancement, let alone given regulatory changes to mobility devices. In order to arrive at estimates for behavioural shift, the analysis has turned to survey results. The shift from cars to e-scooters are based on surveys conducted in Paris, Lyon, Marseille and Lisbon (ITF, 2020). The mode shift from cars to PMDs reported ranges from 8% to 21% and an average of 15% across Europe appears the closest there is to a European estimate.

For shifts from pedestrian and bus, surveys in Nantes, Angers, Paris, Lyon, Marseille, Bordeaux and Toulouse conducted in April 2019 were examined (6t-bureau de recherche, 2019). The percentage of PMD users who reported that they would otherwise have been pedestrians was 44% and the percentage of PMD users who would otherwise have used a bus was 30%. The study appears to be the most comprehensive across Europe and these are therefore adopted as the most accessible European estimates. Nevertheless, there does not appear to be any study that reports robust shift estimates from moped and pedal bikes.

The shift from moped is particularly important. In fact, if no moped journeys were shifted as a result of the policy proposals, there would be more casualties and as a result the proposals would lead to an overall economic burden. This is because of the risk exposure of moped riders on the roads being much higher than other modes. Section 10.7.2 explains the fatalities per billion passenger trips further.

10.7.2. Estimates of mode shift from moped and pedal bike

The shifts from car (15%), pedestrian (44%) and bus (30%) add up to 89%. Based on this estimate, that means for every extra 100 PMD trips, 89 trips would have come from these modes. The overall number of trips taken by all modes is assumed to remain constant, i.e. access to PMDs does not generate any new trips that would not otherwise have occurred.

The analysis therefore focuses on how the remaining 11 trips out of every 100 could have come from moped and bike. In the absence of further evidence on how pedal cyclists would react to the easier access to PMDs, the baseline modelling divides the 11 trips equally between moped and bike. That means the mode shift is 5.5% respectively from moped and pedal bike. It is recognised that the result of economic benefit or cost and is therefore sensitive to these mode shift estimates. In later sensitivity analysis, a break-even assessment is carried out to understand the level of shifts needed for there to be a positive impact economically.

10.7.3. Casualty per billion passenger trips

Having established how transport behaviour would change given the best evidence available, the next step in the modelling exercise is to understand casualty per trips. More comprehensive estimates can be found in fatality than serious or minor injury. Figure 8 of (ITF, 2020) presents the fatalities associated with each of the following modes: moped, pedestrian, bike, car and bus. These data include both those killed while using a particular mode of transport and those who are killed by that mode e.g. pedestrians hit by buses. The current study takes the aggregate fatalities per billion passenger trips caused by each of these modes.

To project the serious and minor injury rates, the ratios in Table 24 are applied to the fatality rate. As can be observed, bus is the safest, followed by pedestrian, PMD, car and moped. The figures show that a trip taken by moped is 28 times more likely to lead to a fatality than one taken on a bus. In addition, PMD is more dangerous than bus and pedestrian as transport modes, so if easier access to PMDs attract users from these means, the society would take up an economic burden in public safety terms. Nevertheless, shifts from moped to PMD, even if slight, would be hugely lifesaving and economically beneficial according to the casualty cost rates above in Table 23.

Table 25: Casualty occurrence per billion passenger trips

	PMD	Car	Pedestrian	Bus	Moped[19]
Fatality	40	50	20	15	425
Serious Injury	928	308	98	200	6,716
Minor Injury	2,360	2,169	342	2,013	23,799

These rates are then also used for the estimation of trip numbers. Mode shift percentage estimates are then applied to arrive at the new number of trips as a result of the easier access to PMDs. Trip numbers increase for PMDs and decrease for other modes in proportions set out in the above subsection.

10.7.4. Casualty projections under policy proposals

The first projection concerns fatalities. In each of traditional modes each year, the number of trips is estimated through dividing baseline projected deaths by the fatality rates above. Those estimated trip numbers are reduced according to the mode shift percentages. These reductions are transferred to the increase in trip numbers of PMDs.

Having confirmed the new trip numbers, they are then multiplied by the respective fatality rates. Furthermore, since many of the baseline projections exhibit improvement in terms of fewer deaths, it appears reasonable that these improvements should also be reflected in the new series post mode shifts. Therefore, in percentage terms, the year-on-year growth in the projected fatalities is also applied on the new projected series under the proposed policy packages. The differences are then obtained for each of these transport modes and displayed in Table 26.

Table 26: Fatality difference assuming self-certification of PMDs (negative means lives saved)

	2021	2022	2023	2024	2025	2026	2027	2028	2029	2030
Car	-70	-251	-259	-267	-274	-281	-287	-293	-298	-303
Pedestrian	-83	-142	-152	-161	-170	-178	-185	-192	-199	-204
Bus	-42	-45	-50	-55	-60	-64	-68	-72	-75	-78
Moped	-219	-244	-270	-294	-318	-340	-360	-379	-396	-411
PMD	375	374	370	359	341	317	289	257	221	183
Total	-39	-309	-361	-419	-480	-545	-612	-679	-747	-814

As can be seen, fewer are projected to die on the road while in a car, as a pedestrian, on a bus or on a moped. This is because there are fewer trips made by these modes due to the shift to PMDs. There are many more lives saved from the shift away from mopeds. This reflects that the higher risk imposed on moped riders. These reductions are partially offset by the increase in deaths associated with increases in trips on PMDs. This does not imply PMDs are more dangerous than mopeds. The opposite is evident, but for the first 5 years, the increase in PMD fatalities outnumbers the decrease in moped fatalities. This is due to the relatively small mode shift from moped to PMD, but also that the baseline moped fatalities without policy proposals are forecast to decline slightly.

Table 27 shows the predicted effect on fatalities of introducing mandatory type-approval for all PMDs over the next ten years. The key effect of this measure would be to supress

[19] 'Motorcycle or moped' in ITF (2019). The moped category in the CARE database appears the most closely aligned with the 'motorcycle or moped' category in the ITF report and without comprehensive evidence in the differences in casualty rates, this study assumes moped is representative of the group.

the growth of the PMD market, which would in turn reduce the size of the mode shift and consequently the effect on casualty numbers.

Table 27: Fatality difference assuming mandatory type approval for all PMDs (negative means lives saved)

	2021	2022	2023	2024	2025	2026	2027	2028	2029	2030
Car	-2	-8	-8	-8	-9	-9	-9	-9	-9	-10
Pedestrian	-3	-5	-5	-5	-5	-6	-6	-6	-6	-7
Bus	-1	-1	-2	-2	-2	-2	-2	-2	-2	-2
Moped	-7	-8	-9	-9	-10	-11	-11	-12	-13	-13
PMD	12	12	12	11	11	10	9	8	7	6
Total	-1	-10	-11	-13	-15	-17	-19	-22	-24	-26

Serious and minor injuries have been dealt with similarly. However, the key difference lies in that the mode shift, expressed in trip numbers, is based on fatality rates. The mode shift approach aligns with fatality because there is available evidence of fatalities per billion passenger trips across modes but not the estimates for serious or minor injuries as far as the authors are aware. This leads to the series differing as the baseline status quo projections come from the Ordinary Least Square (OLS) method. In summary, despite fewer fatalities, the policy proposals are expected to bring more serious injuries in the beginning of the evaluation period overall. The tide would turn in the later years for serious injuries. For minor injuries, there would be a significant reduction in instance overall when the policy is implemented.

10.7.5. Economic cost/benefit from casualty

To arrive at the conclusion as to whether there is an overall economic burden as a result of the policy proposals, the analysis combines the projected casualty differences with the costs of casualty in Table 23 for each of the policy options (Table 28 and Table 29). As we can see, the reduction in fatalities and minor injuries represents economic savings for both policy options throughout the evaluation period from 2021 to 2030. These economic benefits are somewhat offset by the initial increase in the number of serious injuries. In aggregate, the first year under either policy option would see more casualty costs associated with PMD use. This uplift comes from more serious injuries in PMDs not cancelled out by users being sufficiently less exposed in bus, car, pedestrian and moped.

Nevertheless, as the baseline serious injuries in PMDs plateau, the economic cost turns to benefit. These nominal values should not be compared like-with-like, as there is also a discount factor to be considered. A fatality avoided in 2021 in evaluation terms is worth more than the same fatality avoided in 2030 due to time preference attached to present consumption. Discount factors are discussed in more detail in the following subsection.

Table 28: Economic cost (benefit in negative) in billions of Euros from casualty reduction assuming self-certification for all PMDs

Nominal	2021	2022	2023	2024	2025	2026	2027	2028	2029	2030
Fatalities	-€ 0.1	-€ 1.1	-€ 1.3	-€ 1.5	-€ 1.7	-€ 1.9	-€ 2.1	-€ 2.4	-€ 2.6	-€ 2.8
Serious Injuries	€ 2.2	€ 1.2	€ 1.3	€ 1.2	€ 1.1	€ 1.0	€ 0.8	€ 0.5	€ 0.3	€ 0.0
Minor Injuries	€ 0.0	-€ 0.5	-€ 0.7	-€ 1.0	-€ 1.3	-€ 1.6	-€ 1.8	-€ 2.1	-€ 2.4	-€ 2.7
Total	€ 2.0	-€ 0.3	-€ 0.7	-€ 1.2	-€ 1.8	-€ 2.5	-€ 3.2	-€ 4.0	-€ 4.7	-€ 5.5

Table 29: Economic cost (benefit in negative) in Billions of Euros from casualty reduction assuming mandatory type-approval for all PMDs

Nominal	2021	2022	2023	2024	2025	2026	2027	2028	2029	2030
Fatalities	€ 0.00	-€ 0.03	-€ 0.04	-€ 0.05	-€ 0.05	-€ 0.06	-€ 0.07	-€ 0.08	-€ 0.08	-€ 0.09
Serious Injuries	€ 0.06	€ 0.03	€ 0.03	€ 0.03	€ 0.03	€ 0.03	€ 0.02	€ 0.01	€ 0.01	€ 0.00
Minor Injuries	€ 0.00	-€ 0.02	-€ 0.03	-€ 0.03	-€ 0.04	-€ 0.05	-€ 0.07	-€ 0.08	-€ 0.09	-€ 0.10
Total	€ 0.05	-€ 0.02	-€ 0.03	-€ 0.05	-€ 0.07	-€ 0.09	-€ 0.11	-€ 0.14	-€ 0.16	-€ 0.19

10.7.6. Discounting of costs and benefits

A discounting rate to reflect social time preference in is applied in the economic analysis for this study to relate the benefits and costs in future years to the present. This ‘social discount rate’ *r* helps us calculate the present value PV based on the formulation in (Bickel, et al., 2006):

$$PV = \sum_{t=0}^{T} C_t \frac{1}{(1+r)^t}$$

Where *PV* is present value, *t=0* is the starting year, *T* is the number of periods and *r* is the discount rate as mentioned and *C* is the economic cost (or benefit). Recommended social discount rates for EU transport projects in relevant guidelines range between 3% (recommended in the HEATCO project as lower bound for sensitivity (Bickel, et al., 2006) and up to 5.5% (recommended by DG Regional Policy for investments in Cohesion countries (European Commission, 2008).

10.7.7. Resulting Net Present Values

For the central estimate calculations therefore, the average discount rate chosen is 4.25%. Sensitivity analysis is also carried out using a low discount rate of 3% and a high of 5.5%. In all of the discounting scenarios, constant rates are used over time for the evaluation period. This is consistent with the HEATCO recommendations which only call for a declining discount system for proposals that span across generations in very long evaluation periods typically over 30 years. Using the average discount rate of 4.25%, the Net Present Value is -€17 billion, meaning that considering both the casualty and regulatory impacts, the overall economic savings is €17 billion in 2021 prices over the evaluation period of 2021-2030.

10.7.8. Break-even and sensitivity analyses

If the discount rate is at the upper bound, the casualties avoided in the later years of the evaluation period would be discounted more heavily than when using the average discount rate. Using a high discount rate of 5.5% results in an overall economic benefit of €16 billion in 2021 prices. Similarly, a lower discount rate gives more significance to the avoided fatalities and serious minor injuries in the more distant future and hence the Net Present Value would be higher. The associated Net Present Value is €17 billion in 2021 prices. These are summarised in Table 30.

Table 30: Net Present Values under various interest rates and corresponding break-even shifts needed from moped under the self-certification scenario

Discount rate	Net Present Value	Break-even shift from moped
Average - 4.25%	-€17 billion	4%
Low – 3%	-€19 billion	4%
High – 5.5%	-€16 billion	4%

This analysis is furthermore concerned with the required shift from moped to make a positive impact in the economic calculations. The break-even shifts show the percentage of increased numbers of trips from PMDs needed to just result in an overall economic benefit. Using the average 4.25% discount rate, 4% of the increased PMD trips need to come from mopeds which have a much higher rate of injuries than other modes of transport. This also shows that effect of increasing the use of PMDs could have either a positive or negative effect on the numbers of road casualties and their associated costs. In the worst case scenario where no moped users switched to PMDs, the overall economic cost rose to €20 billion in 2021 prices under the average 4.25% discount rate.

It is important to note that this analysis has been conducted with a lot of uncertainty. From the casualty projection to how people might respond to changes in regulatory requirements in relation to PMDs, several significant assumptions and caveats have been made. Moreover, evidence concerning the casualty rates is currently limited, and in extrapolating country-specific data to the European level, the calculations also inevitably ignore the fact that the take-up of, safety of and attitudes toward the use of PMDs will likely vary across member states.

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