

The rise of the speed pedelec, restrained by legislation?

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Summary

Speed pedelecs can count on a growing popularity. With their maximum assistance speed of 45 km/h, they are classified as two-wheel mopeds in the European technical legislation. To minimally adapt type approval regulations for speed pedelecs, extra requirements are introduced for “cycles designed to pedal”. The definition of such cycles includes, among others, a maximum assistance factor of four. The present paper shows that this is not the right tool for defining. Obstacles in national legislation are mainly due to the interpretation of the European technical classification and are related to the position on the road, fiscal incentives and insurance policy.

Keywords: policy, light vehicles, regulation

1 Introduction

The popularity of electric bicycles as an ecological, efficient transportation alternative in cities and densely populated areas is on the rise. Sales numbers confirm this trend: during 2016, 39.2% of bicycles sold in Belgium had an electric motor [1]. The vast majority are classic EPACs, with a maximum assistance speed of 25 km/h and a maximum continuous rated power of 250 W. The restrictions mentioned generate two-wheelers that underperform the speed and climbing ability of young healthy people on sporty bicycles. As a result, the classic EPACs were typically popular with elderly people and mainly used for recreational practice. During the past few years, more and more people (particularly commuters), have opted for the more recently introduced speed pedelecs. These two-wheelers are exceeding one or both of the aforementioned power and speed limitations, enabling higher cruising speeds and thus more attractive for commuters. Belgian vehicle registration numbers for 2016 indicate the clear presence of speed pedelecs on the market: 2041 were registered [2], rather remarkable, compared with the 2235 fully electric cars registered in the same period [3].

On the one hand, policy makers are embracing the introduction of speed pedelecs as a “green vehicle”, on the other hand, the higher maximum speed and power are challenging the boundaries between bicycles and mopeds and consequently both the EU regulations and Belgian legislation.

2 European legislation

The European Union is imposing technical harmonised legislation for vehicles. The classic EPACs are exempt from type approval legislation. However, they must comply with other regulations, such as Machinery Directive [4]. There exists a European Standard (EN15194) that helps EPAC manufacturers to

comply with EU regulations [5]. Speed pedelecs on the other hand, are classified as L-category vehicles and must therefore comply with the type approval legislation, as established in the following 7 regulations:

- 168/2013: the regulatory framework;
- 3/2014: supplementing 168/2013 with vehicle functional safety requirements;
- 44/2014: supplementing 168/2013 with vehicle construction and general requirements;
- 134/2014: supplementing 168/2013 with environmental and propulsion unit performance requirements;
- 901/2014: implementing 168/2013 with administrative requirements;
- 2016/1824: amending regulations 3/2014, 44/2014 and 134/2014;
- 2016/1825: amending regulation 901/2014.

Only the co-decision (168/2013) text [6] is of the European Parliament and the Council, the other regulations are Commission delegated or implementing regulations.

In the co-decision text, all light two-wheel powered vehicles are classified as so-called L1e vehicles. These vehicles have a maximum design vehicle speed of 45 km/h and a maximum continuous rated power ≤ 4000 W. The L1e-vehicle category is divided into two subcategories:

- L1e-A vehicles (powered cycles): Cycles with a maximum assistance speed of 25 km/h and a maximum continuous rated power of 1000W,
- L1e-B vehicles (*two-wheel mopeds*): All L1e-vehicles that cannot be classified as L1e-A.

In practice, most speed pedelecs are limited to an assistance speed of 45 km/h and to a maximum continuous rated power of 350 W or 500 W, classifying them as L1e-B vehicles. To make a distinction in technical requirements for “traditional mopeds” and “bicycle-like vehicles with some moped characteristics”, extra requirements for *cycles designed to pedal* are defined in annex XIX of the commission delegated EU-Regulation 3/2014 [7]:

*Cycles designed to pedal of vehicle category L1e-B shall have a mass in running order ≤ 35 kg and shall be fitted with **pedals** enabling the vehicle to be propelled solely by the rider's muscular leg power. The vehicle shall feature **adjustable rider positioning** in order to enhance the ergonomic posture of the rider for pedalling. The auxiliary propulsion power shall be added to the **driver's pedal power** and shall be less than or equal to **four times the actual pedal power**.*

For these cycles designed to pedal, extra tests for propulsion unit performance requirements are applicable [8], the handlebar stem-assembly, seat-post, front forks and frames of these vehicles have to comply with the standard ISO 4210:2014 [9], and they are exempt from electric range tests [9].

After the EU Commission issued the aforementioned requirements, it was feared that cycles designed to pedal not complying with the requirements above, would be classified as L3e-A1 vehicles (low-performance mopeds), creating legal complications, since it contradicts the L1e-B classification criteria in the co-decision text and the requirements for the L3e-A1 vehicle class are not adapted to these kind of cycles. [10] After the attention of the European Commission was drawn to this issue, they stated that *vehicles with a maximum assistance factor higher than 4, may still be type-approved as a L1e-B vehicle (if they comply with the L1e-B classification criteria)*. [11]

Nevertheless, as a result of Regulation 3/2014, speed pedelecs with an assistance factor higher than four cannot use the type approval procedure adapted for cycles designed to pedal of vehicle category L1e-B. The present paper focuses on the remarkable fact that the use of these adapted technical regulations is related to the rather arbitrary choice of a maximum assistance factor of four. Since the maximum continuous rated motor power is already limited within the L1e-B vehicle category, it is remarkable that a power restriction based on a variable that is depending on the rider's physical capabilities, is introduced. There are other arguments which question the limitation of the maximum assistance factor, such as:

- The limitation of the maximum assistance factor to four causes slower and more fickle speed pedelecs;
- Limiting the assistance factor discriminates weaker riders;
- Testing the maximum assistance factor of a speed pedelec has proven to be difficult;

- Speed measurements indicate that speed pedelecs with maximum assistance factors *higher* than the cited value of four are currently available on the market (type approved according to EC-Directive 2002/24/EC [12]), and are not causing safety issues;
- There is no scientifically established link between the assistance factor and safety;

Since the limitation of the assistance factor for these cycles designed to pedal has been under discussion, the European Commission included the possibility of reviewing this limitation in a future revision of the type approval legislation in Regulation 3/2014. [7]

2.1 The maximum assistance factor versus fickleness and speed

The introduction of a maximum assistance factor, is *de facto* a limitation of the motor power for cycles designed to pedal. This power limitation makes these vehicles more sensitive to environmental factors such as headwind and slopes and limits the maximum achievable speed. In contrast to a real power limitation, the current restriction is a disadvantage to weaker riders. The effect of the limitation of the maximum assistance factor on the “fickleness” (*i.e. the sensitivity to environmental factors*) of the vehicle will be illustrated in this paragraph.

The relation between the rider input power (= the pedalling power) and the steady speed of a bicycle (thus without acceleration) is given by Equation (1) [13]:

$$P_{pedal+motor} = P_{slope} + P_{rolling} + P_{air}, \quad (1)$$

$$P_{pedal+motor} = (m \cdot g \cdot s + m \cdot g \cdot C_R + 0.5 \cdot \rho_{air} \cdot C_D \cdot S \cdot (v + v_{wind})^2) \cdot v, \quad (2)$$

whereby m is the total mass of bicycle and rider in kg, s is the slope, v is the velocity of the vehicle in m/s, v_{wind} is headwind velocity in m/s, ρ_{air} is the air density (1.2 kg/m³ at 16°C at sea level [14]) and the acceleration due to gravity g is 9.81 m/s². For the remaining parameters, values from existing literature [14] have been chosen: a C_R of 0.0060, a C_D of 1.15 and a frontal area S of 0.55 m².

In the literature, values for the pedalling power of an untrained cyclist vary between 75 W [14] and 150 W [15]. In the following simulations an input power of 100 W and a total mass of 100 kg will be adopted.

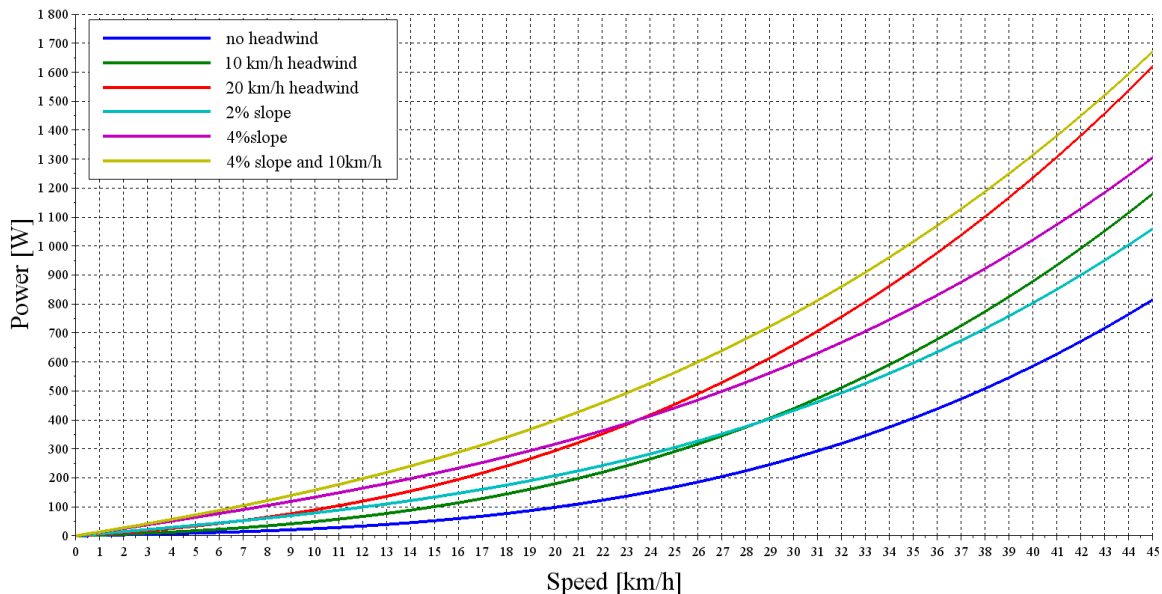


Figure 1: Influence of headwind and slopes on cycling speed

Fig. 1 shows the effect of headwind on the relation between rider input power and vehicle speed. For a rider with a pedalling power of 100 W, the maximum allowed vehicle propulsion power (*motor power + pedal power*) is 500W, allowing the rider to reach 38 km/h if there is no headwind. Even if the rider would pedal 150W, he would not be able to reach the maximum assistance speed of 45 km/h. With a headwind of only 10 km/h, the cycling speed decreases to 32 km/h. If the headwind increases to 20 km/h, which is not uncommon in Belgium [16], the speed of this particular rider is reduced to 27 km/h. The same effect can be observed when a speed pedelec user climbs a slope.

Preliminary results of a survey among Flemish speed pedelec users points out that two (of many) reasons why speed pedelec users choose to buy this vehicle are the “punctuality” (i.e. no time delays because of traffic jams and the possibility to maintain speed, independent of external and physical conditions) and the possibility of cycling to work without being sweaty (even when there is a headwind). However, the simulation above shows that the limitation of the assistance factor makes these vehicles more sensitive to environmental factors, such as wind and slopes. It only allows for stronger riders to reach the maximum assistance speed of 45 km/h and even for them, a sportive effort is required.

2.2 Difficulties in testing the real maximum assistance factor of a speed pedelec

According to the official method for measuring the maximum assistance factor of L1e vehicles designed to pedal [8], the assistance factor of the cycle is measured on a test bench, where a crank drive is simulating the rider’s driving action and a brake or a motor attached to a drum below the rear wheel of the test vehicle to simulate the losses and inertia (*an additional drum is used if the test vehicle is equipped with a front motor*). On such a test bench, the propulsion power of the test vehicle should be measured at the points of operation shown in Table 1.

Table 1: Operation points to test the maximum assistance factor [8]

Point of operation	Simulated rider input power (+/- 10%) [W]	Target vehicle speed [§] (+/- 10%) [km/h]	Desired pedalling cadence [#] [rpm]
A	80	20	60
B	120	35	70
C	160	40	80

[§]If the target vehicle speed cannot be reached, the measurement shall be performed at the maximum vehicle speed reached

[#]Select gear closest to required rpm rate for the point of operation

Subsequently, the maximum assistance factor is calculated with the following formula [8]:

$$Assistance\ factor = \frac{mechanical\ power\ of\ test\ vehicle}{simulated\ rider\ input\ power}, \quad (3)$$

where the mechanical motor power of the test vehicle is the total propulsion power of the test vehicle minus the mechanical input power of the test bench crank motor.

For a speed pedelec with a 350W-motor, the assistance factors at these operating points were measured on a test bench of the company Traktal [17]. The measurement results for operating points A, B and C are shown in Table 2. From these values, it can be concluded that 2.8 is the official maximum assistance factor of the speed pedelec discussed.

Table 2: Measured assistance factors of a 350W speed pedelec

	Point of operation A	Point of operation B	Point of operation C
Test vehicle	2.3	2.6	2.8

To validate this testing method, the assistance factor as a function of the rider input power has been investigated in detail for each of the three operating points.

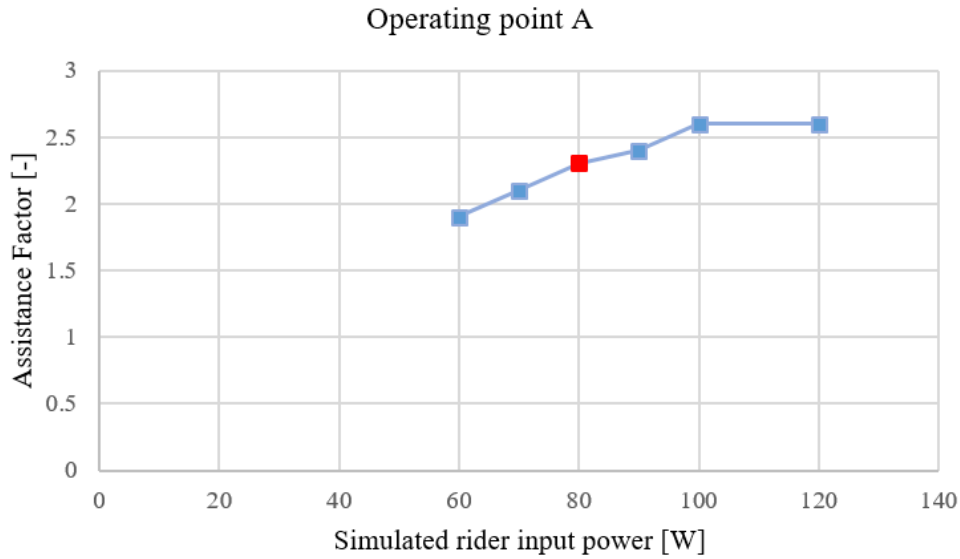


Figure 2: Measured assistance factor in operating point A (in red), varying rider input power

In Fig. 2 the effect of an increase in simulated rider input is shown for operating point A. Hence for these measurements, target vehicle speed is maintained constant at 20 km/h and the pedalling cadence is kept close to 60 rpm. It can be observed that the assistance factor is increasing from 2.3 at a simulated rider input power of 80 W to a factor 2.6 at an input power of 100 W or 120W. A similar relation between the assistance factor and the rider input power can be observed for operating points B & C, as depicted in Fig. 3.

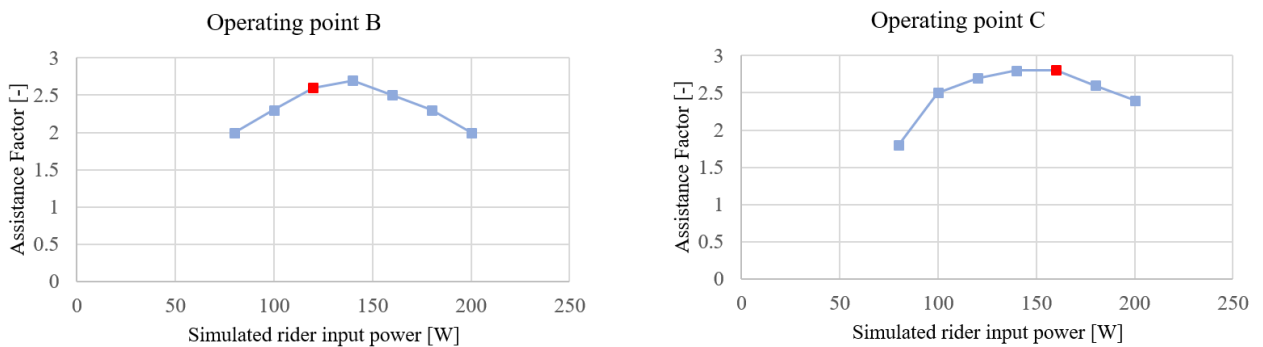


Figure 3: Measured assistance factor in operating points B and C (in red) with varying rider input power

The assistance factor is also depending on the vehicle speed. In Fig. 4, the effect of an increase in speed on the assistance factor is shown. Also for these measurements, the other parameters (simulated rider input power and the pedalling cadence) remain unchanged. The assistance factor is increasing from a factor 2.2 at 18 km/h to a factor 2.7 at 26 km/h, after which it starts decreasing again. Note that values for 18 km/h or for 22 km/h could also be seen as “the” assistance factor for operating point A, since the official testing method allows for a 10% deviation in vehicle speed.

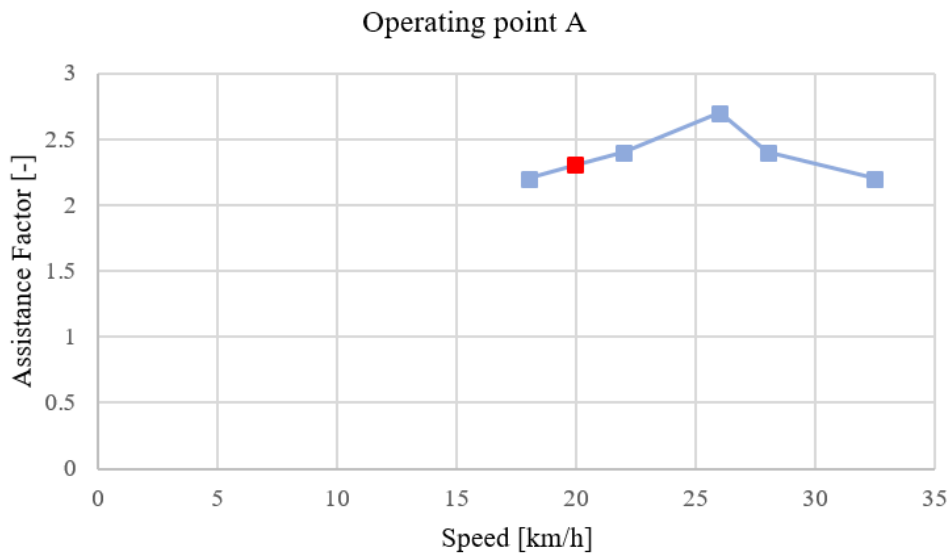


Figure 4: Measured assistance factor in operating point A (*in red*) with varying vehicle speed

A similar observation can be made when varying the speed in operating points B and C, as shown in Fig. 5. It is striking that due to the 10% tolerance interval, 1.1 or 2.8 would both be correctly measured assistance factors for operating point C. It can be expected that this phenomenon occurs at all speed pedelecs to avoid an abrupt stop of assistance once a rider reaches the maximum assistance speed of 45 km/h.

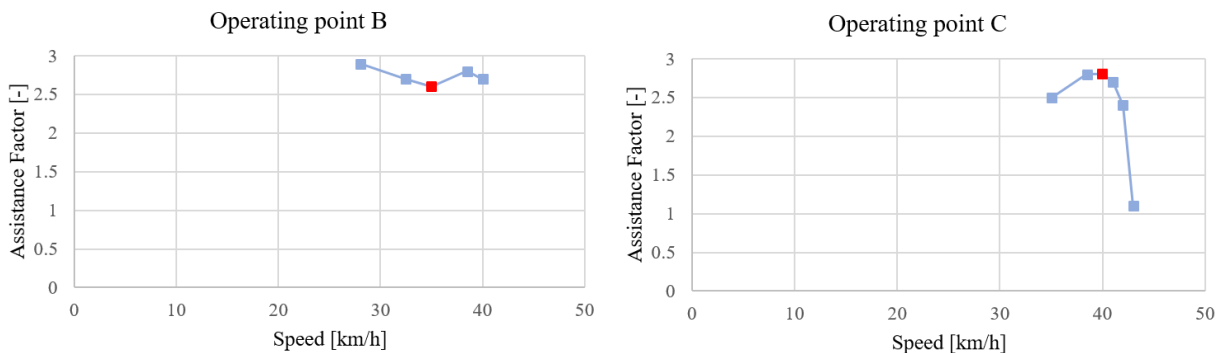


Figure 5: Measured assistance factors in operating points B and C (*in red*) with varying vehicle speed

As shown in Table 2, the maximum assistance factor of the measured speed pedelec would be 2.8, according to the official testing method. Taking advantage of the allowed tolerance interval, it is possible to decrease this factor to a value of 2.6. The highest observed value for the assistance factor (3.1) was measured at a speed of 26 km/h, a simulated rider input power of 100 W and a pedalling cadence of 60 rpm.

The results above show that the official testing method for the maximum assistance factor does not result in the global maximum. It also shows that the tolerance of the test interval allows for deliberately choosing the lowest value in a certain interval, mostly remarkable for operating point C, where it is allowed to measure the relevant assistance factor at speeds up to 44 km/h, where it is expected that all speed pedelecs gradually decrease their motor power to finally cut off at the maximum assistance speed of 45 km/h.

All speed pedelecs currently on the market give the rider the possibility to adjust the motor assistance from zero to a maximum level. A manufacturer using the tolerances mentioned coming up with a speed pedelec with higher assistance factors, will have a substantial advantage in the market since he or she is offering a

vehicle with more control freedom. It is expected that users do not consider this possible higher assistance as a disadvantage since they can always choose in which assistance level they ride.

2.3 Speed pedelecs with higher assistance factors currently available

The maximum assistance factor of 3.1 for 350W vehicles suggests that speed pedelecs with a 500W motor (currently available on the market), have a maximum assistance factor higher than 4. Two commercially available test benches were tried out by two different institutes to go through this procedure, but due to technical incompatibilities it has not been possible yet to verify this. Therefore road measurements were used to get an idea of the assistance factor of these vehicles.

The variation in cruising speed (defined as “the speed at which most distance is covered” [18]) of different speed pedelec users is depicted in Fig. 6. It shows that the median of the cruising speed for speed pedelec users with a 350 W vehicle is 34 km/h and 39 km/h for speed pedelec users with a 500 W vehicle.

Using the power-speed relation from equation (2) and assuming a pedalling power of 100 W, it can be estimated that a motor power of 275 W is needed to maintain the cruising speed of 34 km/h. To cycle at a cruising speed of 39 km/h, a motor power of 445 W is needed, what supports the statement that currently speed pedelecs with assistance factors higher than four are commercially available. This is legally possible since most current speed pedelecs are type approved according to the previous Directive (2002/24), where no benefits were related to a limitation of the assistance factor.

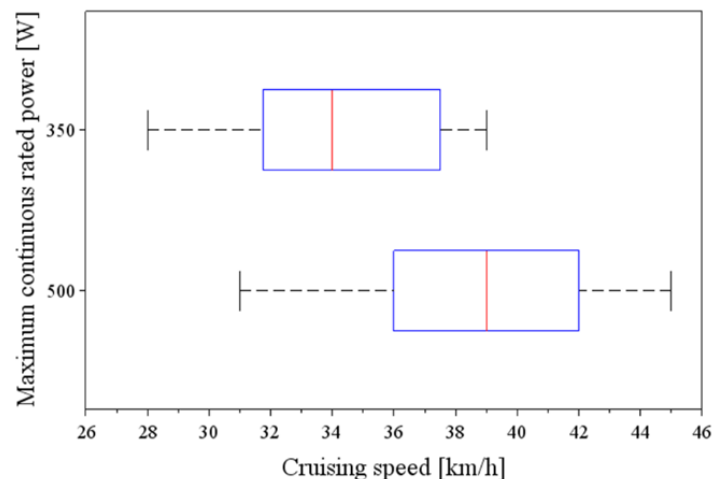


Figure 6: Cruising speed ranges for 350W and 500W speed pedelecs [18]

2.4 Link between safety, maximum assistance factor and control

In recent research, carried out at the Technical University of Hamburg – Harburg (TUHH) was concluded that the limitation of the assistance factor is *imperative, especially for starting in dense traffic, during cornering or for low speed cruising (< 15 km/h) in residential streets* [19]. This statement neglects the intervention of a control algorithm that is capable of setting the motor power. The most important parameter that influences starting and riding at low speeds is the control algorithm for the mechanical assistance, and not the assistance factor. Even the simplest control technique, only based on a speed sensor measurement, has the inherent possibility of lowering the assistance factor at the start, cornering and low speeds. An abrupt control will make it difficult to handle the bicycle, even at low assistance factors. The research from TUHH mentions bad riding experience on speed pedelecs with a higher assistance factor, due to the switching on and off of the motor, especially at lower input powers. It is important to notice that this behaviour was observed on testing vehicles where the software was modified to implement a very rough control algorithm (“bang-bang control”), thus these vehicles were no production types. In fact, this is stressing that a smooth control of the power delivered by the motor is more important than a limitation of the assistance factor. In

discussions with speed pedelec users the experience of better control on vehicles with a higher assistance factor was generally preferred.

Remarkably, in the conclusions of this earlier research the emphasis was on possible safety issues caused by high assistance factors at low speeds (below 15 km/h), but the official testing method for the maximum assistance factor is not mapping the assistance factor at these speeds. Thus higher assistance factors at these low speeds are possible under the current legislation.

A last observation is that the non-limiting of the assistance factor is not causing safety issues for traditional pedelecs with a maximum speed of 25 km/h, even though their peak motor power is not limited. Thus, also for these vehicles, assistance factors higher than four are possible. There seem to be no reasons why a high assistance factor would cause more safety issues for speed pedelecs.

3 Local legislation

The rules concerning speed pedelecs usage (traffic code, age limits, helmet obligations...) are jurisdiction of the EU member states [20]. The European classification and the transition from Directive 2002/24 to Regulation 168/2013 has some repercussions on this local legislation. Due to the European classification as a L1e-B vehicle (thus as a “two-wheel moped”), most EU member states opted to consider the speed pedelec as a moped in their traffic codes. Some member states, such as Belgium [21], created a new, dedicated moped category, other member states, such as the Netherlands [22], chose not to distinguish between speed pedelecs and traditional mopeds. As a result of this classification, speed pedelec riders generally have to ride on the same place on the road as mopeds, even though they have lower cruising speeds, as shown in Fig. 6. In Belgium, another consequence of this classification is that speed pedelec riders could not automatically benefit from fiscal measures, such as bicycle reimbursements, subsidies or tax deductions. Currently, the government acknowledges the difference between traditional mopeds and speed pedelecs and announced that they will make these incentives also applicable for speed pedelec users [23].

As mentioned in Paragraph 2.3, most available speed pedelecs are still type approved under the previous Directive 2002/24, where they were generally classified as “*low-performance mopeds*”. To be eligible for this classification, the possibility of driving at a speed <25 km/h without pedalling had to be added to these speed pedelecs. The industry preferred this adjustment over type approving them as “two-wheel vehicles” (the former L1e category), because the latter was not adapted for this kind of vehicle. This technical detour has consequences for the insurance legislation. In Belgium, a motor vehicle insurance is required if a vehicle can be solely propelled by a motor [24]. Speed pedelecs need thus extra insurance, even though many users are not aware of this obligation, which is a serious issue. It is expected that speed pedelec manufactures will no longer integrate the possibility of riding without pedalling in new models that will be type approved under Regulation 168/2013, thus these vehicles won’t be subject to this compulsory motor vehicle insurance.

It is important that member states thoroughly consider the status of the speed pedelec and clearly inform (future) speed pedelec users. Achieving a modal shift to more light, electric, active mobility, is one of the challenges for the coming years. The speed pedelec can play an import role in this transition, however their “just a moped”-label could be hindrance for their breakthrough.

4 Conclusion

The speed pedelec is classified as a two-wheel moped in the European technical regulations. In order to make use of the adapted type approval procedure for cycles designed to pedal, the vehicle requires adjustable rider positioning, its weight is limited to 35 kilograms and the maximum assistance factor is limited to a factor four. The last requirement mentioned is contested since this limitation is causing slower and more fickle speed pedelecs, it discriminates weaker riders, the official testing method is not guaranteeing to measure the real maximum assistance factor, the controllability is not taken into account, and there is no scientific link between the assistance factor and vehicle safety. A complication, among others, in the Belgian legislation is the classification of speed pedelecs as mopeds, which is affecting both financial incentives and their position on the road. The conditions for a type approval under the former EU-Directive result in a compulsory motor

vehicle insurance in Belgium, a fact where few users are aware of. A reasonable and clear legislation is necessary for a breakthrough of this promising technology that can foster the modal shift from cars to light electric vehicles and that can contribute to more sustainable, liveable, healthier cities and to a more active population.

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Guylian Stevens graduated in 2016 as electrotechnical engineer at KU Leuven. In his master's thesis he modelled the link between speed pedelec, driver and the environment. Currently he is working as a researcher at the E&A research group at KU Leuven, in which he is dealing with speed pedelec research.



Bart Huyck graduated in 2002 as master in mechanical engineering at the University College KAHO Sint-Lieven. In 2004, he completed an additional course on biomedical and clinical engineering at the university of Gent. After his studies, he joined the Energy and automation (E&A) research group of the Katholieke Univeriteit Leuven (KU Leuven). In 2013, he finished his PhD on model predictive control at KU Leuven. Currently, he's working as a postdoctoral researcher of the E&A research group. His research interests are on the interface of model predictive control, light electric mobility, photovoltaic energy measurements and security of industrial networks



Emilia Motoasca obtained a PhD-degree in electrical engineering from Delft University of Technology in 2003. Between 2003 and 2013 she worked at the Eindhoven University of Technology, Faculty of Electrical Engineering, as post doc and later on as assistant professor. In 2015 she joined the research group Energy and Automation at KU Leuven as assistant professor with research interests in design and modelling of electric motors and drives applied to robotics, e-mobility and industrial processes.



Jan Cappelle graduated in 1999 at KU Leuven as electrical engineer with a master thesis at the National Technical University of Athens (Greece). In 2008 he successfully defended a PhD on the performance analysis of electric bicycles at the Vrije Universiteit Brussel. Later that year he started his own research group E&A that integrated in the cluster of the KU Leuven department ESAT and steadily grew to the staff of 20 people of today. In 2014 he became an associated professor at the faculty of engineering technology. His research interests include stand-alone power systems, light electric mobility and photovoltaic energy measurements. He was co-organizer and host of the first workshop on electrical bike commuting (WeBikeC), held in Ghent in 2016.