Suitable solutions and EU regulatory framework of electric light mobility vehicles for last-mile delivery: an overview

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Suitable solutions and EU regulatory framework of electric light mobility vehicles for last-mile delivery: an overview

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Abstract. Due to current environmental European regulations in terms of pollutant emissions, electric cargo cycles are receiving growing interest compared to heavy-duty vehicles as a cheaper and healthier alternative for last-mile delivery of goods in urban and suburban areas. Within the PNRR Next Generation EU program, the Sustainable Mobility Center aims to design innovative e-cargo bikes considering technical features along with rider behaviour and infrastructure characteristics. The market offers plenty of solutions, which may differ in technical and design features. Nowadays a standardized terminology, widely shared among researchers for those light mobility vehicles does not exist. Several authors employ different terms or introduce classifications based upon the vehicle type of use or even on the vehicle layout (e.g., payload position or number of wheels). Concurrently, EU regulatory framework is undergoing rapid changes and appears unclear. Certain categories of light mobility vehicles might be ruled out from the type-approval system established by the regulation EU 168/2013. For those vehicles, harmonised standards are under drafting or approval. This situation requires a considerable effort among manufacturers in the identification of the proper product directives or regulations and the associated mandatory requirements and testing procedures for the introduction of a new vehicle model in the market. Within this context, an overview of the EU regulatory framework for these light mobility vehicles is presented. A literature evaluation with a structured and coded methodology of scientific databases, company websites and commercial reports is performed, evaluating commercial and prototype solutions of e-cargo bikes from a technical and legislative perspective. Furthermore, a case study is addressed, deepening the national legislation which rules the use of e-cargo bikes in Italy. The information provided in this work may be useful among manufacturers as a starting point for the design process of these types of vehicles. Moreover, this paper lays the foundations for a widely recognized taxonomy of e-cargo bikes based upon distinctive features.

1. Introduction

Transport accounts for nearly a quarter of Greenhouse Gas (GHG) emissions in the EU (European Union) and stands as the primary contributor to urban air pollution [1]. Within this sector, road transport is the largest emitter, responsible for over 70% of EU GHG emissions from transport in 2019 [2] and entails negative impacts as accidents, traffic congestion, and noise pollution [3]. Furthermore, road transport contributes significantly to the production of pollutant emissions, as sulphur dioxide (SO2), nitrogen oxides (NOx), carbon monoxide (CO), unburned hydrocarbons (HC) and particulate matters (PM) [3]. Passenger cars and vans, including light commercial vehicles, are responsible for approximately 12% and 2.5% of the total EU carbon dioxide (CO2) emissions, which is the primary GHG [2]. The European Commission proposes ambitious targets for new vehicles, requiring a minimum 55% reduction in net GHG emissions for cars and vans by 2030 [4], as part of its efforts to attain climate neutrality by 2050, in alignment with the European Climate Law [5].

Urban mobility of people and goods has a substantial impact on air quality of urban and suburban areas with high population density and, together with the problems related to traffic congestion, parking issues as parking space and parking time, air pollution and noise pollution, has a relevant effect on the quality of life [6]. Moreover, the accessibility to city centres for conventional vehicles is restricted or prohibited (e.g., low emission areas, pedestrian areas, or time windows). In this sub mentioned framework, electric light mobility vehicles appear as a viable solution to mitigate or partially solve the negative effects of the transportation systems [7]. Among these vehicles, the most popular are e-bikes, also known as pedelecs (pedal electric cycles) or EPACs (Electric Pedal Assisted Cycles). However, a sustainable solution that is increasingly appearing in the urban environment, particularly in European countries, is the so-called e-cargo bike [8]. This light mobility vehicle is environmentally friendly and has the potential to replace private cars or commercial vehicles, further than other cycle-like vehicles [9]. Indeed, it does not result in any local emissions and has a limited urban surface usage. Moreover, it reduces costs compared to using a van [10], [11], [12] and in several situations is competitive to a conventional vehicle in terms of travel kilometres or time [13]. Within this context, e-cargo bikes are receiving growing interest for last-mile delivery of goods in urban and suburban areas [12], [14]. The expression “last-mile delivery” refers to the final delivery service route that covers a range of a few kilometres in a city environment, after large volumes of items are unloaded from trucks at strategical logistic points (e.g., distribution centres or logistic hubs) near or just outside cities. To date e-cargo bikes are particularly suitable for densely populated urban and suburban areas when logistic hubs are close to the city center [15].

Several models are available in the market or under development, mainly classified in macro-categories (two-, three- and four-wheeled). Technical details for each existing or feasible layout are not fully exposed and a standardised taxonomy does not exist. Moreover, relevant features from a regulatory perspective or related to the usage of these light mobility vehicles within the EU member states are not highlighted. European standards are yet to be established [16], [17]; the regulatory framework is not properly defined, and the presence of regulatory gaps is observed. In addition, current literature does not explore country-specific restrictions on the use of e-cargo bikes within the EU member countries [8].

This work focuses on a specific e-cargo bike category, similar to an EPAC, with the following characteristics:

- maximum continuous rated power is less than or equal to 250 W;
- electric assistance switches off when the cyclist stops pedalling;
- electric assistance is progressively reduced and finally switched off before the vehicle reaches the velocity of 25 km/h.

Furthermore, the presence of a trailer as and additional equipment to increase the transported payload is not considered in this paper.

As explained in detail in Section 3, e-cargo bikes that meet these conditions can be placed on the market without European type-approval. However, the CE marking process is mandatory and the manufacturer is required to follow a conformity assessment procedure.

Within the PNRR Next Generation EU program, the Sustainable Mobility Center [18], Light and Active Mobility Spoke aims to design innovative e-cargo bikes, considering technical features along with rider behaviour and infrastructure characteristics; a target is the introduction of a small fleet of e-cargo bikes for last-mile delivery of mails and packages in Italy. This work is functional for the project design, and aims to:

- identify commercial or prototype e-cargo bikes layouts, to determine the most relevant features from a regulatory perspective or related to the vehicles usage and to introduce a classification based upon distinctive characteristics;
- investigate the EU regulatory framework to identify European directives, regulations, and standards, along with the homologation workflow, and to present the existing issues;
- determine and explore the national legislation in Italy, to ascertain whether and how usage rules of e-cargo bikes are applied within the national territory.

The information provided in this work, beside constituting a solid foundation for the reference project, may be useful among manufacturers as a starting point for the design process of these light mobility vehicles.

2. Materials and methods

A literature evaluation with a structured and coded methodology of scientific databases, company websites and commercial reports is performed, reviewing commercial and prototype solutions of e-cargo bikes in the EU-27 (i.e., the twenty-seven member states of the European Union) from a technical and legislative perspective. Several keywords Three scientific databases were consulted: Scopus, ScienceDirect and Google Scholar. The desired data were mainly obtained by visiting the websites of e-cargo bikes manufacturers and component manufacturers, as powertrain components. The consultation of the user manual, often available in the "support" or “download” section of the manufacturer website, was frequently required. For each identified layout, the following data were collected and further analysed, as described in section 3:

- name of the e-cargo bikes manufacturer;
- name of the EU member country;
- name of the e-cargo bike model;
- vehicle layout;
- type of use;
- vehicle price;
- vehicle dimensions;
- unloaded vehicle weight;
- admissible payload;
- cargo box dimensions;
- cargo box capacity (i.e., weight and volume);
- powertrain features;
- vehicle range;
- tyres size;
- European product directives and regulations identified by the manufacturers;
- standards applied to guarantee the product conformity with the EU directives and regulations.

EU directives, regulations and standards are listed in the declaration of conformity, which is usually available in the “support” or “download” section of the manufacturer website, as a part of the user manual or as a single document.

Concurrently, the EU regulatory framework is explored by employing similar keywords in two primary sources: the official website of EU law and other public documents of the EU (EUR-Lex) [19] and the official website of the European Commission (EC) [2]. To find out relevant European directives, regulations, and standards for the product “e-cargo bike” it was necessary to identify the "entity" of the product, which included the intended use and the list of components along with their functionalities.

Each relevant directive, regulation and standard is identified by reviewing the title and the "scope" section.

Finally, the Italian legislative acts for e-cargo bikes usage within the national territory are identified and a review is performed, focusing on several topics:

- vehicle classification;
- vehicle requirements;
- infrastructure characteristics;
- infrastructure compatibility and usage rules.

3. Results

E-cargo bikes may lead researchers and manufacturers to ambiguity under several topics. The market offers numerous solutions, which differ from each other in a wide range of technical features; only overall data are available, and a standardised classification for these light mobility vehicles is absent.

Concurrently, EU regulatory framework is not properly defined and is undergoing rapid changes; European standards are still under drafting or approval. Moreover, no standard exists for the definition of an e-cargo bike within EU member states. Therefore, it is up to the individual countries to establish a proper definition. Within this context, Italian legislation provides sufficiently concise requirements and usage rules for e-cargo bikes within the national territory.

3.1. Layout identification of e-cargo bikes

Based on the several studies analysed, the keyword "e-cargo bike" is the main term for denoting this category of vehicles, although it is frequently used in a general manner rather than being specific to a particular layout. The existing or under development solutions can be broadly divided in three macro categories, based on the number of wheels: bicycles or bikes (i.e., two-wheeled/r layouts), tricycles or trike (i.e., three-wheeled/r layouts) and quadricycles or quads (i.e., four-wheeled/r layouts) [8].

Approximately seventy companies were identified and more than a hundred of e-cargo bike models, mainly two- wheeled and three-wheeled layouts, while only a few numbers of four-wheeled layouts are available in the market. Figure 1 represents a map chart with a sequential two colours gradient, providing information on EU manufacturers of e-cargo bikes; among the twenty-seven member countries the manufacturing is active across eleven, mainly in central and northern Europe. Germany is the country with the highest number of manufacturers, followed by the Netherlands and Denmark. Figure 2 shows the number of the models identified for each macro category.

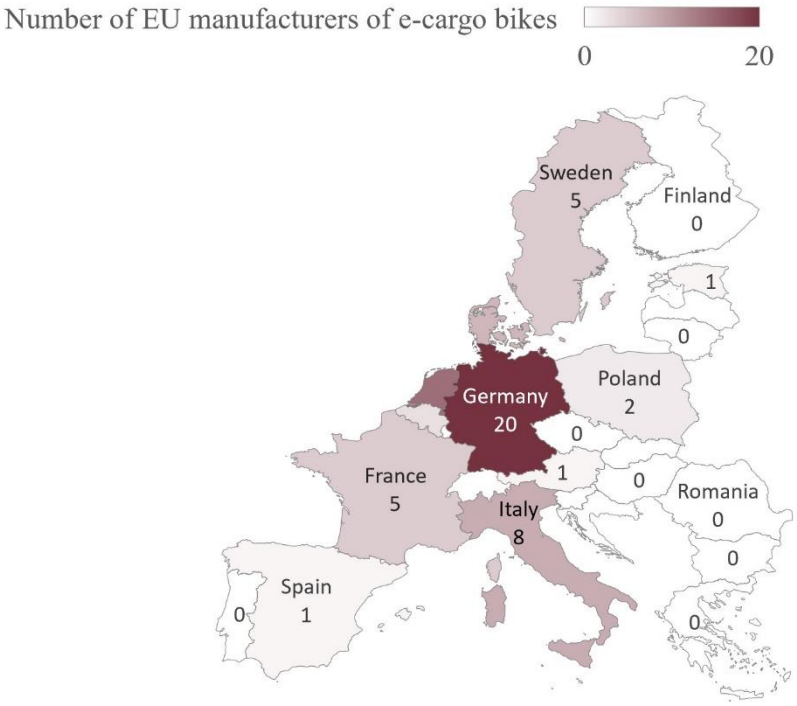


Figure 1. Map chart of EU e-cargo bike manufacturers. Adapted using graphical data powered by GeoNames, Microsoft, OpenStreetMap and TomTom.

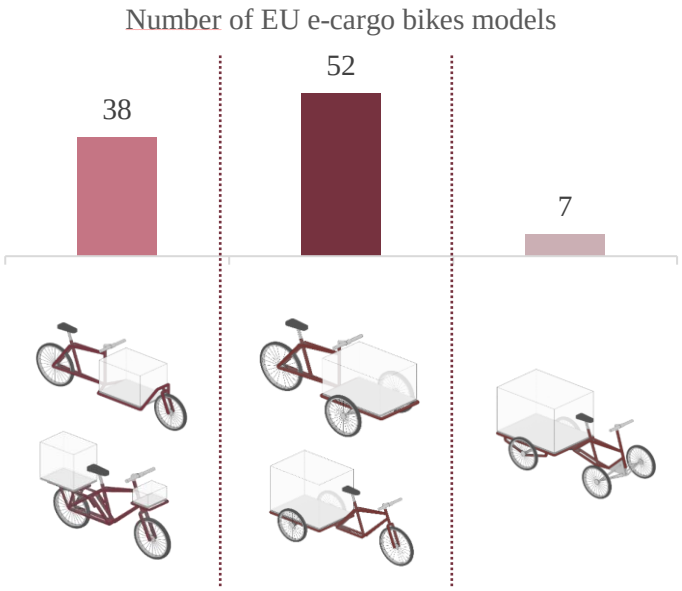


Figure 2. Number of EU e-cargo bike models and design representation of the macro categories.

Among the three macro categories, e-cargo bikes differ from each other by several overall features [9], [13], [20], [21], as shown in Figure 3:

- curb weight [kg]: this parameter represents the weight of the assembled vehicle without considering the rider, the cargo box, and the payload;

- admissible payload [kg];
- cargo box capacity [l];
- range [km]: this parameter is declared by the manufacturers and represents the average km travelled with a single battery. If a dual battery is implemented, it theoretically doubles;
- price [€].

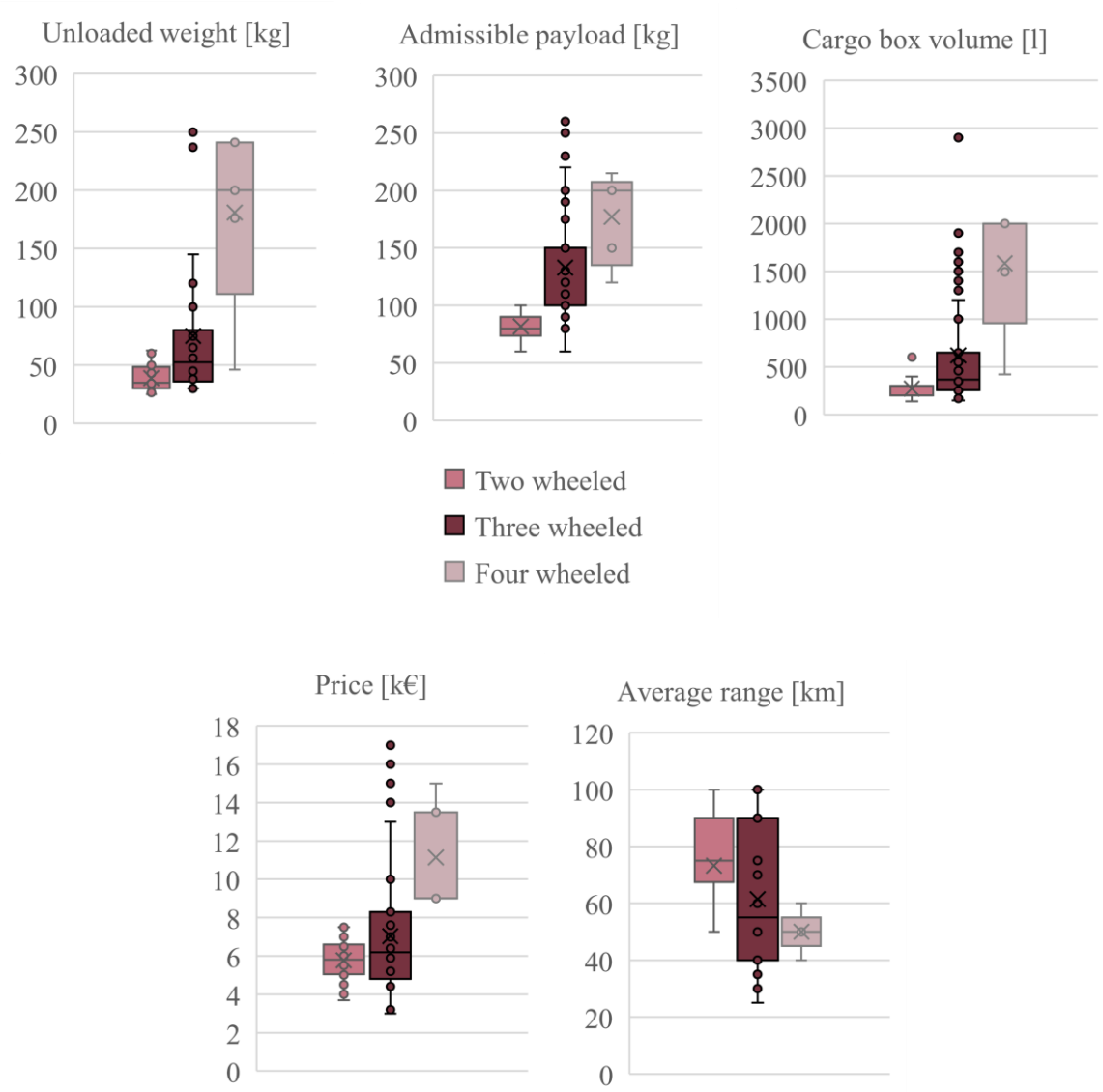
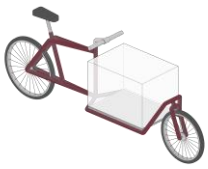
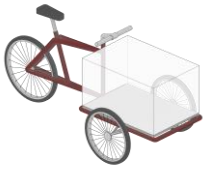
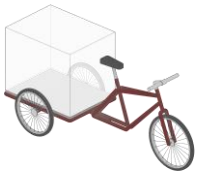
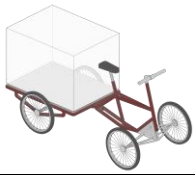


Figure 3. Overall features of e-cargo bikes.

Each macro category comprises several layouts and a different terminology is used among researchers to identify each layout. These terms are summarized in Table 1.

Table 1. E-cargo bikes layouts: terminology

Category	Load position	Layout	Terminology	Reference
Two wheeled	Front		Long Jhon bike Front-load(ing) cargo bike	[13] [12], [21]
	Rear		Delivery bike Messenger bike Conventional bike	[13] [12] [22]
	Rear		Long Tail bike Rear-load(ing) cargo bike	[13] [12], [21]
Three wheeled	Front		Front load tricycle Front-load(ing) cargo trike Tadpole tricycle	[13] [12], [21] [16]
	Rear		Heavy-load tricycle Heavy-duty cargo bike Freight tricycle Rear-load(ing) cargo trike Delta tricycle	[13] [23] [24] [12], [21] [20]
Four wheeled	Rear		Four-wheel cargo cycle Quad or quadricycle Cargo Quadracycle	[25] [22], [26] [21]

The existing layouts differ by several features, as listed below:

- number and position of the wheels: in the case of a two-wheeled and a four-wheeled layout, these are similar, respectively, to a bicycle and a quadricycle. Otherwise, a three-wheeled layout may have two different configurations, commonly known as tadpole and delta layouts [16], [20]; these are distinguished by the position of the two-wheeled axle, which is frontal for the tadpole layout and rearward for the delta layout;
- position of the cargo box: respect to the rider, the position of the payload can be forward (front load) and backward (rear load);
- dynamics: four different configurations were identified: Tilting (T), Tilting All Frame (TAF), Tilting Front Frame (TFF) and Not Tilting (NT). An e-cargo bike with a tilting all frame is designed with a tilting mechanism that allows the tilting of the entire frame, while

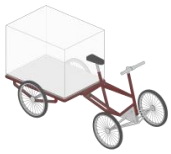
a tilting front frame implies the tilting of the front frame respect to the rear side of the vehicle, mainly consisting of the rear frame connected to the rear wheels. Instead, a not tilting layout has a rigid frame that prevent the rolling motion;

- driving wheel/s: three different options were identified: Front-Wheel Drive (FWD), Rear-Wheel Drive (RWD) and All-Wheel Drive (AWD);
- steering wheel/s: two different options were identified: Front-Wheel Steering (FWS) and Rear-Wheel Steering (RWS).

Despite each of these features may contribute to the classification of individual layouts, it was observed that the main distinctive and useful features for defining the taxonomy of e-cargo bikes are those related to the axles of the vehicle. The proposed classification considers the number of wheels of each axle and the dynamics of the axles. Nevertheless, the identification of the axle that is most heavily loaded due to the payload (i.e., the load position), adds details. In the case of a two-wheeled layout, there are only two possible configurations (i.e., front load and rear load), while a four-wheeled layout has the cargo box always positioned above the rear axle. In the case of a three-wheeled layout, the payload is often positioned above the two-wheeled axle, and only in special cases it can be placed on the one-wheeled axle. The nomenclature used for the identification of each layout consists of two pairs of two characters, separated by a horizontal dash. The first two characters provide information about the front axle, while the second two characters refer to the rear axle. For each pair of characters, the first indicate the number of wheels on the axle, while the second is related to dynamics of the axle; T and R stand, respectively, for Tilting and Rigid. As further integration, the information related to traction and steering are included in the nomenclature. The proposed classification is presented in Table 2.

Table 2. E-cargo bikes layouts: classification and taxonomy

Loaded axle	Dynamics	Layout	Nomenclature
Two wheeled layout – E-cargo bike or bicycle			
Front	Tilting		1T – 1T (RWD – FWS)
Rear	Tilting		1T – 1T (RWD – FWS)
Rear	Tilting		1T – 1T (RWD – FWS)
Three wheeled layout – E-cargo trike or tricycle			
Front	Not tilting		2R – 1R (FWD – RWS)
Front	Not tilting		2R – 1R (RWD – FWS)

Front	Tilting All Frame		2T – 1T (RWD – FWS)
Rear	Not tilting		1R – 2R (RWD – FWS)
Rear	Tilting front frame		1T – 2R (RWD – FWS)
Rear	Tilting all frame		1T – 2T (RWD – FWS)
Four wheeled layout – E-cargo quad or quadricycle			
Rear	Not tilting		2R – 2R (F/R/AWD – FWS)

3.2. EU regulatory framework of e-cargo bikes

3.2.1. Regulation EU 168/2013

E-cargo bikes do not have their own definition within EU regulatory framework, although they can be considered part of the broader category of “cycles”, primarily covered by regulation EU 168/2013 on the approval and market surveillance of two- or three-wheel vehicles and quadricycles [27]. This regulation replaces directive CE 2002/24 [28], that in article 1, letter h, explicitly excluded "cycles with pedal assistance which are equipped with an auxiliary electric motor having a maximum continuous rated power of 0.25 kW, of which the output is progressively reduced and finally cut off as the vehicle reaches a speed of 25 km/h, or sooner, if the cyclist stops pedalling", and their components or technical units unless they were intended to be fitted to vehicles covered by the directive. Regulation EU 168/2013 broadens the scope of exclusion, given that it does not apply to "pedal cycles with pedal assistance which are equipped with an auxiliary electric motor having a maximum continuous rated power of less than or equal to 250 W, where the output of the motor is cut off when the cyclist stops pedalling and is otherwise progressively reduced and finally cut off before the vehicle speed reaches 25 km/h," as specified in article 2, paragraph 2, letter h. Exemption from the application of the regulation generally means that vehicles can circulate without being subject to type-approval, thus without requiring a helmet, a license plate, a driver license, and a mandatory insurance for damages resulting from the operation of the vehicles. However, individual EU member states may still introduce further limitations, especially those aimed at ensuring road safety, both in terms of additional product requirements or controls and vehicle circulation rules, which should be considered in the design phase of each individual vehicle. As a result, the EPAC is exempt from the approval procedure, provided that it complies with the requirements imposed by regulation EU 168/2013. This is further supported by harmonised standard EN 15194: 2017, that defines an EPAC as a "cycle, equipped with pedals and an auxiliary electric motor, which cannot be propelled exclusively by means of this auxiliary electric motor, except in the start-up assistance

mode." Within this context, e-cargo bikes, which fall within the category of "pedal cycles" as described by regulation EU 168/2013, are exempt from type-approval.

3.2.2. Safety obligations and conformity assessment procedure

E-cargo bikes not covered by regulation EU 168/2013 are nevertheless encompassed within the framework of a well-defined and comprehensive set of European directives and regulations aimed at ensuring the safety of products entering the European single market. Within this context, the New Legislative Framework (NLF) is in force since 2008 [29]. It comprises a series of measures designed to enhance market surveillance and improve the quality of the conformity assessment procedure, that is the process undertaken by a manufacturer to demonstrate whether specific requirements related to a product are met before it can be sold. This process may involve a conformity assessment body, as required by the applicable legislations, known as notified body, responsible for conducting tasks related to the conformity assessment procedure. EU product legislation outlines the conformity assessment procedure for each product and manufacturers are legally obligated to comply with EU directives and regulations.

However, in some cases they are allowed to self-certify the product compliance. To simplify this process, the manufacturers may use harmonised standards, which are drawn up specifically as a useful tool for the manufacturer to demonstrate product compliance with EU legislation. This means that if the product complies with harmonised standards, the presumption of conformity with the reference EU directives and regulations is ensured. On the other hand, as these are voluntary standards, the manufacturer has the option to select an alternative technical approach to establish compliance with the obligatory legal standards, even if it might result in higher expenses to ensure the presumption of conformity. Harmonised standards are developed by the European Committee for Standardisation (CEN), the European Committee for Electrotechnical Standardization (CENELEC), and the European Telecommunications Standards Institute (ETSI), officially designated by the European Union and the European Free Trade Association as responsible entities [30]. The references to harmonised standards must be published in the Official Journal of the European Union (OJEU) [31]. Manufacturers are responsible to carry out the conformity assessment procedure, set up the technical file, issue the Declaration of Conformity and affix the CE marking to a product. Within this context, the binding EU directives and regulations for e-cargo bikes are listed below; the main harmonised standards that may be applicable are also reported. As already mentioned, the list cannot be neither complete nor exhaustive.

1) Machinery directive (2006/42/EC) [32], as the e-cargo bike falls under the scope of the directive as a “system powered by a force other than direct human or animal force, composed of multiple parts, one of which is mobile”, pursuant to article 2. This directive includes a comprehensive list of essential health and safety requirements concerning the design and construction of machinery. E-cargo bikes can only be placed in the market if compliant with these requirements. This directive has already been replaced by a new community regulation [33], [34] that, however, will not be effective until forty-two months after its publication (i.e., 2027), although some rules are already effective.

   The main harmonised standard is EN 15194:2017, specifically designed for EPACs. Compliance with this standard does not allow the product to be compliant with the machinery directive regarding the essential safety requirements relating to hand-arm and whole-body vibrations transmitted by the vehicle to the user. The proposed solutions to overcome this issue are listed below:

   - identify harmonised standards under the machinery directive that cover safety requirements on user vibrations, as EN 1032:2003+A1:2008;
   - identify not harmonised standards, with the awareness that compliance with those documents does not give presumption of conformity to the machinery directive (e.g., EN ISO 5349-1 and EN ISO 5349-2).

2) Electromagnetic compatibility directive (2014/30/EU) [35], as there are electric devices that may influence each other when interconnected or close to each other. The purpose is to keep all those side effects under reasonable control; most of these requirements are covered by EN 15194: 2017.
   This directive has recently been modified, although only regarding the electromagnetic compatibility of control circuit devices, actuating elements, and multimedia equipment, which must currently comply with implementing decision 2021/455 [36].
   An example of a harmonised standard is EN IEC 60947-5-2020.
3) Low voltage directive (2014/35/EU) [37], as there is electrical material (i.e., the battery charger) intended to be used within the limits indicated by the directive, specifically with a nominal voltage in the range 50 - 1000 V in AC and between 75 - 1500 V in DC.
   An example of a harmonised standard is EN 60335-2-29: 2021.
4) Battery directive (2006/66/CE) [38], that rules the collection, recycling, treatment and disposal of batteries and accumulators. Since batteries may contain metals such as zinc, copper, manganese, lithium, and nickel, which may be dangerous for the environment and human health, this directive prohibits the placing on the market of most batteries and accumulators with a certain mercury or cadmium content. It has been already subject to revision through the introduction of a new regulation, which will take effect, for most of its content, next year [39].
5) WEEE Directive (2012/19/EU) [40] on WEEE (Waste Electrical and Electronic Equipment), that is aimed at improving the collection and recycling of the said waste.
6) REACH Regulation (EC 1907/2006) [41], relative to the REACH (Registration, Evaluation, Authorisation and Restriction of Chemicals); through the consultation of the available declarations of conformity of EU e-cargo bikes manufacturers it emerges that only in a few cases it has been deemed appropriate to comply with this regulation, without normally assuming any relevance.
7) Display Regulation (EU 2019/2021) [42], as there may be a display intended to show driving data to the user; however, it only applies when the display area is greater than 100 square cm.
8) RoHS Directive (2011/65/EU) [43], that lays down rules on the RoHS (Restriction of the use of Hazardous Substances in electrical and electronic equipment (EEE) for the protection of human health and the environment, including the environmentally sound recovery and disposal of EEE waste. E-cargo bikes may not contain any lead, mercury, cadmium, hexavalent chromium, polybrominated biphenyls (PBB) or polybrominated diphenyl ethers (PBDE), that can be found in several components (e.g., battery or frame).
   An example of a harmonised standard is EN IEC 63000: 2018.
9) Radio Equipment Directive (2014/53/EU) [44], as there may be radio equipment (e.g., Bluetooth or Wi-Fi devices).

The identified EU directives and regulations do not express obligation for the manufacturers to rely on notified bodies, hence they can carry out individual tests and checks independently. Nevertheless, many manufacturers turn to professional testing organizations to test e-cargo bikes. As already mentioned, it should be emphasized that the listed standards do not adapt completely to e-cargo bikes, as to date a standard definition for e-cargo bikes do not exist. Within this context, the European Committee for Standardisation has established the working group “carrier cycles” to develop European standards for e-cargo bikes, which are still under drafting or approval. The status of the European standardization process is documented in the working programme on the CEN webpage, in the section “Technical Work” [45]. At national level, two member states have issued ad-hoc standards for safe design and construction of e-cargo bikes. France released NF R30-050 standard in 2018 and Germany released DIN 79010 standard in 2020, both aimed at providing rules and tests for e-cargo bikes with defined maximum transportable weight, length, electric motor power (i.e., 250 W) and speed (i.e., 25 km/h). Within this context, these two national standards lay the foundation for the European standardisation process under development by CEN.

3.3. E-cargo bikes in Italy: a case study

E-cargo bikes, as extensively explained, belong to the broader category of "cycles". Following the Italian legislation, the reference standard is the legislative decree 285/1992 [46] and subsequent amendments. Article 50, paragraph 1, first part of the legislative decree defines the "cycles" as vehicles with two or more wheels, operated exclusively by human power and by means of pedals. Thanks to a recent amendment, article 50 also includes in this category electrically pedal assisted cycles, equipped with an auxiliary electric motor with a maximum continuous rated power of 0.25 kW, whose power supply is progressively reduced and eventually interrupted when the vehicle reaches 25 km/h, or earlier if the cyclist stops pedalling. Therefore, the national legislation is in line with the regulation EU 168/2013. Furthermore, the law 178/2020 [47] allows to equip these vehicles with a button for activating the motor while the pedals are stationary, although in this mode the vehicle must not exceed a velocity of 6 km/h. Moreover, national legislation has recently introduced provisions for electrically pedal assisted cargo cycles, as specified in article 50, paragraph 1, second part of the legislative decree 285/1192, according to which cargo cycles can be equipped with an auxiliary electric motor with a maximum continuous rated power of 0.5 kW. However, the provision regarding the increased motor power prescribed for the cargo version of the cycle appears to be in contrast with EU regulation 168/2013, which limits the maximum continuous rated power at 0.25 kW. Therefore, only the cargo cycle with a 0.25 kW power should be considered exempt from EU type- approval. Paragraph 2 specifies the maximum cycle dimensions, prescribing that it cannot exceed 1.3 m in width, 3.5 m in length, and 2.2 m in height. Moreover, it establishes that cycles must have an approximately flat and horizontal loading platform, open or closed, whose loading surface complies with the following criteria:

$$Surface_{loading\ platform} \leq 0{,}3 \cdot Length_{cycle} \cdot Width_{cycle} \quad (1)$$

For the design of e-cargo bikes or any other cycle-like vehicles, it is also necessary to assess the regulations of public roads. To date EU regulations are absent, except for directive EU 2019/1936 [48] on road infrastructure safety, which applies to the trans-European transport network (TEN-T).

In Italy, traffic regulations for these vehicles and the provisions related to the different parts of the infrastructure are of particular importance, as listed below:

- cycle lanes: currently there are two types, as defined by article 4 of ministerial decree 557/1999 [49]: cycle lane "on site" and "on reserved lane". The former is physically separated from the road or the sidewalk by physical barriers and can be one-way or two-way, while the latter is almost one-way and can be obtained as a part of the road or the sidewalk, separated from vehicular or pedestrian traffic by means of a longitudinal delineation stripe. Article 7 specifies the lanes dimensions, which must be at least 1.5 m wide (including markings) for a one-way cycle lane and 1.25 m wide per lane in the case of a two-way cycle lane, resulting in a total width of 2.5 m. Although these values are the standard dimensions for cycle lanes, the width can be reduced to 1 meter per lane;
- cycling and pedestrian area: this is primarily dedicated to pedestrian traffic. According to article 189, cyclists are not obliged to use this shared path;
- pedestrian area: this is defined as the "area prohibited to the circulation of vehicles, except for those in emergency service, bicycles, and vehicles serving individuals with limited or impaired motor abilities, as well as possible exceptions for zero-emission vehicles with dimensions and speeds comparable to bicycles". Unless otherwise specified by the local authority through the placement of road signs, cycles are allowed to travel within pedestrian areas. However, article 182 recommends pushing the cycle by hand whenever, due to traffic conditions, it may obstruct or represents a danger to pedestrians;
- pedestrian pathway: this is exclusively for pedestrians. Therefore, there is no allowance for cycles circulation, except when they are being pushed by hand;

- cycling and vehicular pathway: this represent the most dangerous scenario for cyclists and can only be implemented when there is insufficient space to create a dedicated cycle path. However, the legislation purpose is to promote shared spaces, as confirmed by the legislative decree 67/2020 [50].

Considering the results of the market analysis described in Section 3 in terms of cycle size and loading platform area dimensions, an assessment with the requirements imposed by Italian legislation is shown in Figure 4 and Figure 5. As a result, only one model exceeds the admissible length, while for the loading platform area of several models does not respect the condition imposed by Equation 1.

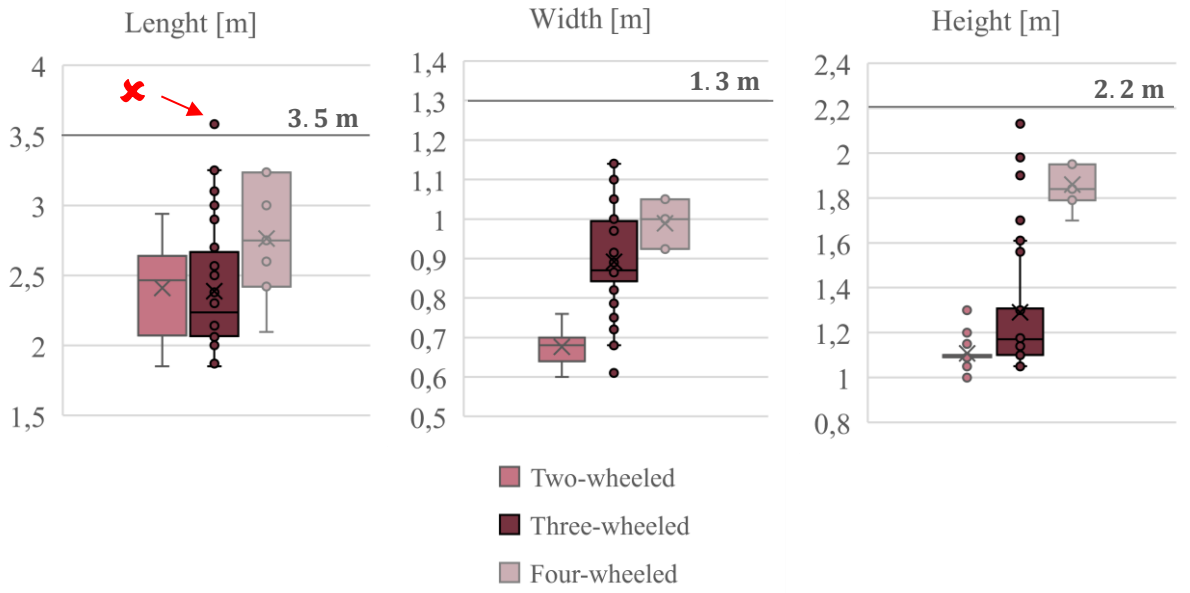


Figure 4. Comparison of e-cargo cycles models dimensions from commercial analysis with the size limitations imposed by Italian legislation for cycles dimensions.

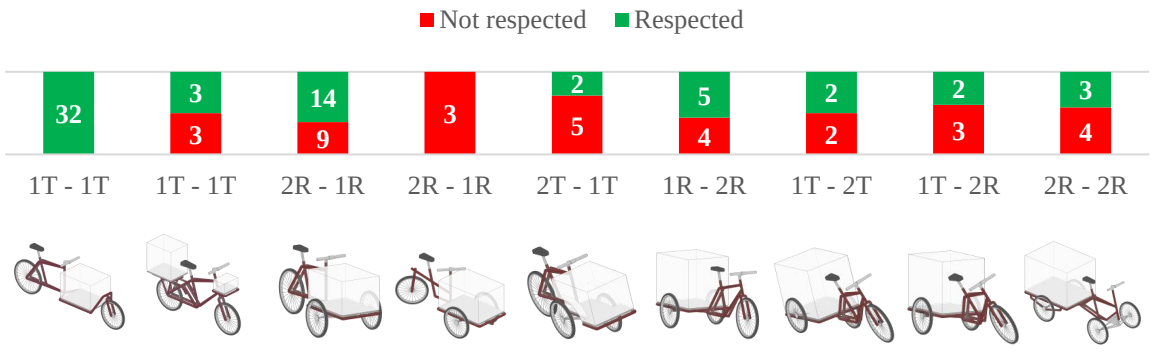


Figure 5. Graphical representation of e-cargo cycles models from commercial analysis which respect or not the condition imposed by Italian legislation regarding the loading platform surface of cargo cycles.

4. Conclusions

The work presented in this paper focused on the framework of e-cargo bikes considering existing or under development layouts from a technical and legislative perspective. In addition, EU regulatory framework is outlined. Furthermore, a case study is addressed, deepening the Italian legislation on the use of these light mobility vehicles within the national territory.

A literature review with a structured and coded methodology aimed to identify the main existing issues related to this topic is performed. The results show that, to date, a standardised terminology for e-cargo bikes is absent. The taxonomy of e-cargo bikes is explored, and a classification based upon distinctive features is presented. The European regulatory framework was also analysed. The work highlighted a lack of an e-cargo bike definition and, consequently, of specific standards, although there is ongoing work in the standardization committees. The current EU regulatory framework is explained and the feasible European product directives and regulations, along with harmonised or not harmonised standards were identified. As, for the design phase, the assessment of national legislation on the use of these vehicles has to be considered, the Italian relevant laws were also identified and presented.

The study performed in this paper represents a baseline for to project performed within the Sustainable Mobility Center, Light and Active Mobility Spoke, and may be useful among researchers and manufacturers as a preliminary step for the design phase of these light mobility vehicles.

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