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E-BIKE USE IN URBAN COMMUTING: EMPIRICAL EVIDENCE FROM THE HOME-WORK PLAN

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Abstract:

A substantial part of the environmental issues relies on fossil fuels. This dependence is crucial in transport even though many incentives and interventions have been proposed to reduce pollutant emissions. Electric vehicles with zero emissions might represent a viable solution in urban areas. Many cities encouraged modal shift policies from cars to an e-bike or car-sharing/pooling with electric vehicle fleets. This paper reports the ongoing outputs from a pilot project, relying on a modal shift to the e-bike, promoted in the city of Messina (Southern Italy) by the Ministry of Ecological Transition. The objective is to assess, in the territorial context of Messina, the e-bike as a competitive transport mode in terms of social awareness of eco-friendly mobility solutions. The available dataset consists of about nine months of observations; data on total distance and trips have been gathered for each e-bike. It emerged how, in a typical working day, the average distance travelled is about 6.9 km, the usage rate for working days is about 81 %, and the carbon dioxide reduction is about 245 kg per person each year. During the project, information was also collected on the satisfaction with the e-bike and the quality of travel. It emerged that regular bicycle use has good repercussions on the interviewees' psycho-physical well-being, reducing the stress factor connected with urban mobility. Despite mechanical breakdowns and the lack of an infrastructure dedicated to active mobility representing a limitation, travel comfort and safety are two latent variables that are transversally valid within the population; about 15 % became familiar with the e-bike and made it their primary mode choice for everyday activities. In this sense, outputs represent a starting point for future policies and give back adjustments before introducing similar services to students from the university and second-grade schools.

Keywords: *e-bike, sustainable mobility, environment, mobility management, micromobility*

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1. Introduction

In Italy, in 2019, road transport is responsible for 30 % of total CO_2 emissions (Figure 1). Focusing on road transport, it produces the 92.64 % of the CO_2 generated by all transport modes; (ISPRA, 2022a). In addition to this, other issues must be considered due to traffic, like noise, accidents, and congestion, that impose the implementation of less intrusive transport modes (Comi et al., 2022; Bebkiewicz et al. 2021). The European Commission promoted the sustainable urban mobility and developed guidelines to implement sustainable urban mobility plans (SUMP, 2019), extended also to freight transportation (Comi et al., 2020). Moreover, the introduction of an effective and sustainable urban mobility plan requires the introduction of an adequate set of indicators to assess the goals achieved (Russo & Comi, 2010; Chamier-Gliszczyński & Bohdal, 2016) as well as the analysis of the complete life cycle of an urban transport system (Chamier, 2011). At the same time, the concept of Smart Cities focused on new technologies as a service to improve urban mobility (Rindone, 2022; Russo, 2022; Vitetta, 2022) and on environmental issues and CO_2 emission reduction through the introduction of electric mobility alternatives (Janecki & Karoń, 2014). Consequently, the rise of electric bikes (e-bikes) opened new opportunities in urban mobility, both for the private and public transport. Concerning private transport, some studies (Nigro et al. 2022; Musolino 2022; de Haas et al., 2021; Di Salvo et al., 2020; de Kruijf et al., 2019; Cairns et al., 2017, Sosnowska, 2012) pointed out user's behaviour in using the e-bike for travels (e.g., travels home-work-home). Concerning public transport (Bieliński et al., 2021; Radzimski & Dzięcielski, 2021; Ma et al., 2018), the topic relies on the shared e-bikes and their use (e.g., if the travel is performed only by the e-bike or if the e-bike is used for accessing/egressing to other transport systems). Moreover, e-bikes are among the recommended transport means by the World Health Organization (World Health Organization, 2018) as a tool to tackle physical inactivity to reduce illness and other harmful effects of sedentary behaviour. Therefore, some authors have analysed this type of transport mode on health (Brüchert et al., 2021; Langford et al., 2017) also considering the potential users that can decide to use e-bike. E -bike represent an interesting alternative to complete the coverage of public transport networks representing a promising solution in promoting multimodal mobility, (Chamier, 2012; Caggiani et al. 2020).

The use of e-bike as an alternative transport means respect to the car also bring other benefits. For example, the reduction of road traffic (fewer cars and fewer environmental impacts) with has a general positive effect on other vehicle categories indirectly affects other travel characteristics, like route choice (Di Gangi and Polimeni, 2022; Di Gangi et al., forthcoming), travel time and parking. Besides, the e-bike use could be a determinant for supporting the development of crowd-shipping (Ermagun & Stathopoulos, 2018; Punel et al., 2018). Of course, as also stated by (Krukowicz et al. 2021) exists a strong relationship between traffic volume and cycling infrastructure.

In this project, a case study where the e-bike is available as a new transport mode (i.e., alternative to the car) to perform daily travels is analysed. The study area is the city of Messina (south Italy), in it, some citizens have been involved in a pilot project relying with a modal shift from car to e-bike. The objective is twofold:

- to analyse the e-bike as a competitive and sustainable transport mode able to respond to economic, social and environmental needs;
- to evaluate the current situation of the offered service to bring out the strengths and weaknesses.

Concerning the former, a procedure is used to assess the possibility to support sustainable development by evaluating impacts and system performances. About the second objective, an analysis on the use of the system is performed, and some possible improvements are proposed to optimize the offered service.

The available data consist of nine months of observations (between September 2020 to April 2021) and, for each e-bike (61 users are involved in this phase of the pilot, for a total of about 1,400 surveyed travels) daily total distance and path choices have been gathered.

The paper is structured as follow. Section 2 reports a brief literature review. In Section 3, the approach used is described, while Section 4 reports the dataset and the data analysis. Finally, in section 5 some conclusions and possible future developments are drawn.

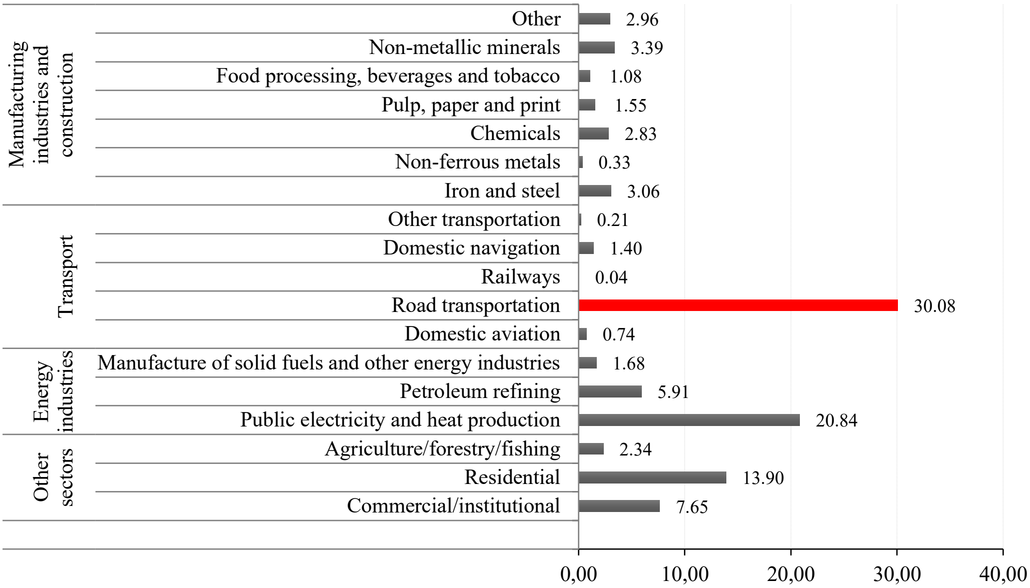


Fig. 1. Carbon dioxide emission in Italy in 2019 (Source: elaboration from ISPRA, 2022)

2. Literature review

The replacement of the car with the e-bike could significantly reduce the CO_2 emission, Philips et al. (2022) estimate that, under some constraints, the use of e-bikes in England could the CO_2 from cars of about 25 million tonnes per year. McQueen et al. (2021), focusing their observation on the city of Portland, demonstrate that the modal shift (15 % from car to e-bike) would reduce the level of CO_2 of about 225 kg per capita per year. Astegiano, et al. (2019) analyse the impact of e-bikes on modal split and, consequently, on emissions in urban areas. Considering different time horizons and different e-bike penetration shares, the conclusion is that the CO_2 reduction range from 0.2 % to 0.7 % with respect to current situation. The modal shift before and after the purchase of an e-bike in Netherlands is examined by Sun et al. (2020) pointing out that the reduction in the car use is of about 10 %. Rérat (2021), shows the results of a survey from which it emerges that the use of e-bike (since is possible to improve the carrying capacity and to increase the travelled distance) encourage users to use this transport mode. The environmental benefits linked with the use of e-bikes are investigated in Elliot et al. (2018), where a life cycle assessment approach is implemented to evaluate the impacts related to the modal shift from car to e-bike. Similarly, Liu et al. (2021) evaluate the life cycle environmental impacts of batteries for e-bikes, by considering different types of batteries. An analysis on the CO_2 reduction is reported in McQueen et al. (2020) which consider two components: the first one related to the modal shift and the second one related to the production of the electricity needed to charge the battery of e-bikes. In a similar way, the study of Winslott Hiselius & Svensson (2017) highlights the environmental benefits (in terms of CO_2 reduction) of using the e-bike instead of the car. Philips et al. (2022) propose a microsimulation approach to estimate the (theoretical) capability to reduce emissions when trips by cars are replaced with trips by e-bikes. Bucher et al. (2019) analyse the case in which commuters use e-bike; different hypothetical scenarios are considered to evaluate the reduction in pollutant emissions, and in general the introduction of policies towards the use of electric mobility instead results beneficial for the reduction of the exhaust emissions (Jacyna et al., 2021).

The safety of e-bike riders is another topic treated in literature, also by considering the e-bikers perception of the safety (Haustein & Møller, 2016), similarly weather conditions represent a focus point that could drive decision to use or not bicycle in general

(Pazdan,2020). The risk awareness of cyclists is analysed by Wang et al. (2018), in it authors point out that many e-bikers have no knowledge of safety and traffic rules. Chang et al. (2022) explores the injury severity of accidents occurred to e-bikers in relation to road traffic, environmental variables, type of crash and rider demographic attributes. A comparison between the accidents involving e-bike and traditional bikes is reported in Siman-Tov et al. (2018), where is pointed out that the accident rate for e-bikes is lower than for traditional bikes, anyway injury severity is higher. Similarly, Panwinkler & Holz-Rau (2021) explore the causes of e-bike accidents and the factors influencing they severity with the goal to individuate the measures to adopt to reduce the impacts. Liu et al. (2022) propose a method for the reconstruction of accidents involving cars and e-bikes. Hertach et al. (2018) study the case of single vehicle accidents with e-bikes, investigating the causes of accidents (e.g., speed, skidding, road slippery). Hu et al. (2020) explore the relation between e-bike rider casualty and impact speed when an accident occurs.

The e-bikes sharing systems (e-BSSs) are currently adopted around the world (Galatoulas et al., 2021). A first classification emerging from literature relies with the system configuration, which can be dockless or docked (Lazarus et al., 2020; Luo et al., 2019; McKenzie, 2018). Bieliński et al. (2020) evaluate how an e-bike sharing system affect the user modal choice. In the considered study area, this study finds that in zones with high population density the best solution is a dockless system, whereas in suburbs a docked system could be implemented. Chen et al. (2020) propose a docked system and formulate a bi-level model to individuate the position of the sharing stations, whose correct dimension and collocation, to ensure an appropriate level of integration, needs a preliminary analysis above the identification for different categories of road network (Żochowska, et al. 2021). Zhao et al. (2019) analyse the effects of the transport infrastructures, the demographics, and the built environment indicators on e-bike reallocation in a docked system in order to identify the parking areas where it is necessary to reallocate the bikes, and similarly Caggiani et al. (2018), proposed an analysis on a free-floating system, where bikes can be delivered or picked-up almost everywhere in the network and not just at dedicated docking stations also suggesting a methodology able to generate spatio-temporal clusters of the usage patterns of the available bikes in every zone of the city (Caggiani et al. 2017). Fukushige et al. (2021) analyse the modal shift when the sharing system is dockless, it emerges how the modal shift is relevant for short trips. He et al. (2019) investigate the attributes influencing the choice of e-bike share (docked), it emerges how wheatear conditions, population density, and public transport presence affect the choice of this transport mode.

Another not negligible aspect, even if not further investigated in this work, is the use of e-bikes for freight transport in urban areas (Comi & Savchenko, 2021; Nuzzolo et al., 2018). The use of bikes for urban freight transport was implemented in many cities (Marujo et al., 2018; Conway et al., 2017) and the transition to e-bikes is underway (Narayanan et al., 2022; Llorca & Moeckel, 2021; Sheth et al., 2019). Taefi et al. (2015) analyse the willingness of transport companies to use electric vehicles (also e-bikes) in urban freight transport by distinguishing different transport segments. Gruber et al. (2014) analyse the electric cargo bike as a potential new vehicle for urban freight transportation evaluating the willingness of drivers to use these vehicles.

From literature emerges how the e-bike use was investigated, highlighting some aspects related to environmental benefits, safety, organisational and operational aspects, and mode choice. This paper fits into the topic of modal split (from car to e-bike), also analysing the environmental benefits (in terms of pollutant reduction) in the case in which the user is free to make is choice among e-bike and the other available transport modes. The proposed approach allows us to evaluate how the modal shift from car to e-bike affects the pollutant emissions in the study area.

3. Approach

The main goal of this study is to analyse how e-bikes as a means of transport for home-work-home travels might reduce air pollution. However, the benefit could be relevant also for delivering e-parcel within urban areas. A procedure to evaluate the saving in pollutant emission is needed. Therefore, the approach used to assess the environmental benefits of e-bikes instead of cars. The models considered in this point are taken from ministerial prescriptions adopted in Italy. As stated before, the goal of the procedure is twofold: to evaluate the savings in fuel consumption and then to estimate the reduction of emissions (carbon dioxide, CO_2; carbon monoxide, CO; nitrogen oxides, NO_x and particulate matter PM_{10}).

Figure 2 reports the general approach. During the pilot experiment users demand for car and e-bikes travels have been supervised. A set of *emission factors* (coefficients which quantify the unitary emissions) is considered in relation to the *vehicle fleet*. The outputs are two: the *savings in fuel consumption* and the *savings in emissions*.

The savings in fuel consumption are evaluated as (Ministero della Transizione Ecologica, 2022):

$$C = 0.01 \cdot R_{car} \cdot \alpha \cdot \gamma \tag{1}$$

where:

- R_{car} is the daily reduction of travels by car because of the use of e-bike and it is calculated as follow:

  $$R_{car} = \frac{N}{\delta} \cdot d$$

  where:
  - N is the average number of users (per day) shifting from car to e-bike,
  - δ is the average number of users per car,
  - d is the average daily travelled distance, in km.
- α is the average consumption of a car (liters/100 km);
- γ number of days in the reference period.

The general formulation to evaluate the emission reduction is:

$$E_x = 0.001 \cdot R_{car} \cdot \varphi_x \cdot \gamma \tag{2}$$

where φ_x is an average value of the emission factor (depend on the vehicle park), the subscript x indicates the type of pollutant (CO_2, CO, NO_x and PM_{10}).

4. Data and analysis

Messina (Sicily, South Italy) is a city of about 220,000 inhabitants, (ISTAT, 2022), on a surface of about 214 square kilometres. A pilot project was launched in 2020: a sample of citizens was invited to use e-bikes instead of a car. The original project was to consider only the home-work-home travels; anyway, as it emerged from the analysis, the users enjoyed using it even on the weekend. As shown in the distance travelled in the working days during the pilot is 81 %, and the remaining 19 % is almost equally divided between Saturday and Sunday.

4.1. Data analysis

The pilot study involved 61 citizens from September 2020 to April 2021 for a total amount of 185 days (32 of these are holidays) and, in this time, the bikes have been used 1,357 times (i.e., more than 7 trips for day). In Table 1 (and in Figure 3a) the number of travels by month and day are reported. It is possible to note a decreasing in the use after the month of September (in this month the number of travels is of about 35 % with respect to the total), this is due to Covid-19 restrictions into red zones areas; indeed, starting from October, the city experimented a local lockdown. Figure 3b reports a cross between number of travels and weather conditions, as expected most of the travels are on dry weather conditions (about 60 % in working days and about 15 % in weekend).

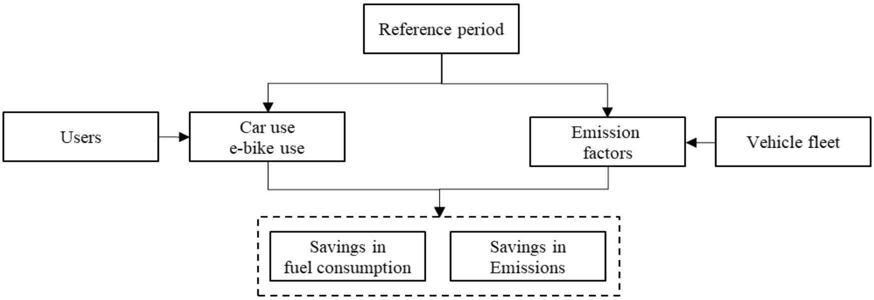
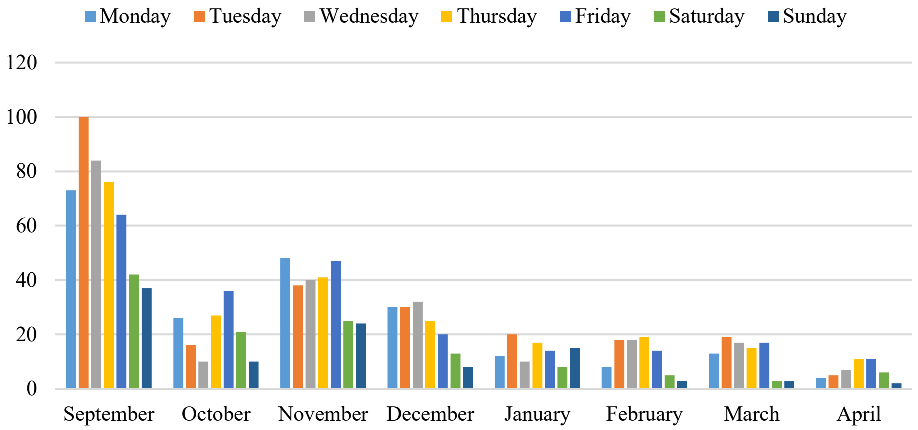


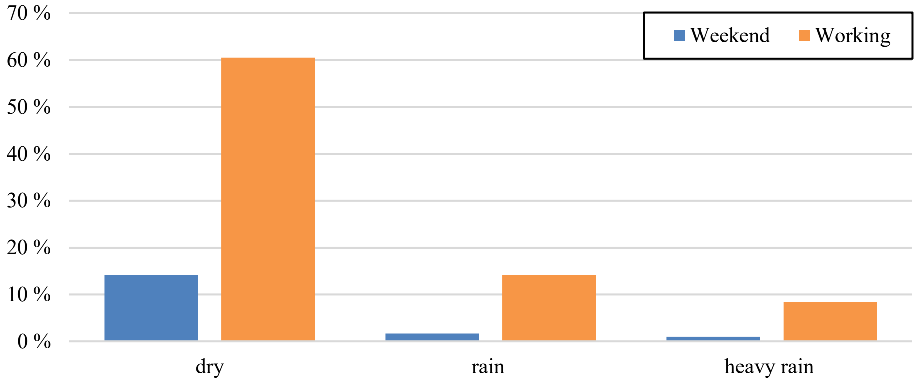
Fig. 2. The applied procedure

Table 1. Use of e-bike: number of times (September 2020-April 2021)

	Monday	Tuesday	Wednesday	Thursday	Friday	Saturday	Sunday	**Total**	**%**
September	73	100	84	76	64	42	37	**476**	*35*
October	26	16	10	27	36	21	10	**146**	*11*
November	48	38	40	41	47	25	24	**263**	*19*
December	30	30	32	25	20	13	8	**158**	*12*
January	12	20	10	17	14	8	15	**96**	*7*
February	8	18	18	19	14	5	3	**85**	*6*
March	13	19	17	15	17	3	3	**87**	*6*
April	4	5	7	11	11	6	2	**46**	*3*
Total	**214**	**246**	**218**	**231**	**223**	**123**	**102**	**1357**	*100*
%	*16*	*18*	*16*	*17*	*16*	*9*	*8*	*100*	



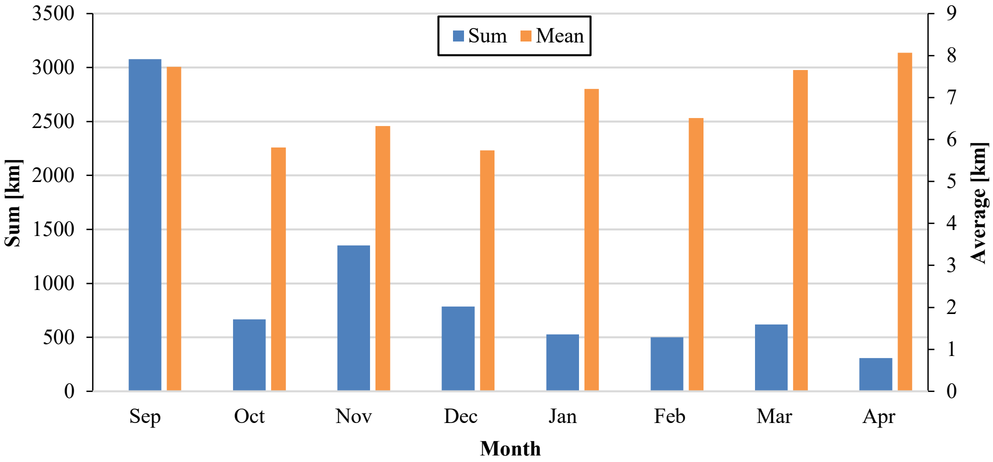
(a) number of travels by month and day



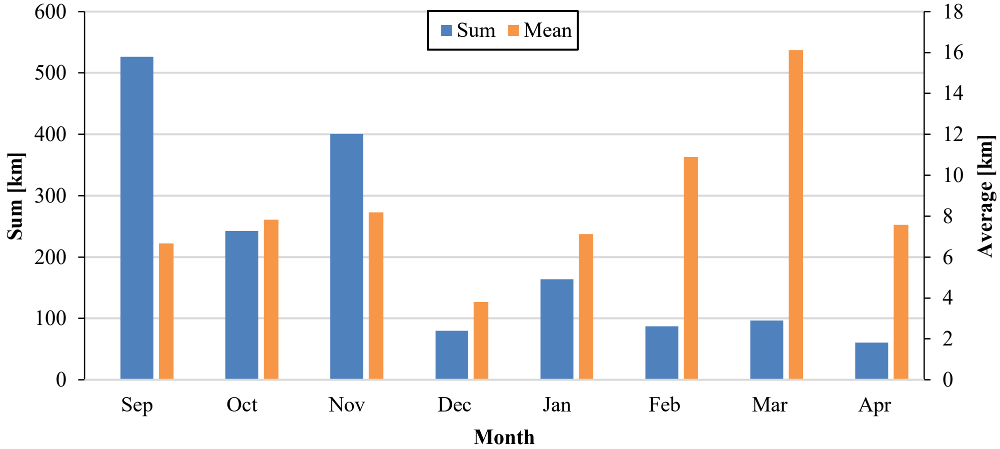
(b) rate of travels by wheatear conditions

Fig. 3. Use of e-bikes

Each e-bike is equipped with a GPS that makes it possible to track the vehicle and evaluate the length of the travel. Figure 4a and 4b report the total and the average values of the travelled distance over working days and during weekends. From this analysis emerges that the total travelled kilometres in the reference period are about 9,500 (about 8,000 in working days, 38 % of them are concentrated in September), the average value range from 5.7 km (December) and 8.1 km (April) for working days and from 3.8 km (December) and 16.1 km (March). Further restrictions due to the spreading of the Covid-infection were introduced at the beginning of December 2021and; because of this, the number of people who choose smart working increased, thus reducing the interest in the plan; this reduction is visible. By considering all travels, the average covered distance is of 7.3 km. The average distance, considering only the travels in working days, is of 6.9 km (consistent whit values from literature, McQueen et al., 2020).



(a) – working days



(b) – weekend

Fig. 4. Travelled distance

The analysis of the travels in relation to the covered distance *d* (Figure 5) pointed out that:

- about the 27 % of the travels are less than 2 km over working days (approximately 20 % at the weekend),
- about the 30 % of the travels range from 2 and 5 km in working days (approximately 24 % at the w.e.),
- about the 24 % of the travels range from 5 and 10 km in working days (approx. 34 % at the w.e.),
- about the 19% of the travels are greater than 10 km in working days (approx. 22 % at the w.e.).

4.2. Emissions and fuel consumption

In this section, starting from the data collected in the survey, savings in fuel consumption (*C*) and emissions (E_x) are calculated following the procedure reported in section 2. Focusing on working days, here the values of the parameters discussed in section 2 are reported in Table 2.

Table 2. Parameters

$\alpha^{(*)}$ [lt/100km]	γ	$\delta^{(*)}$	$\varphi_{CO2}^{(\#)}$ [g/km]	$\varphi_{CO}^{(\#)}$ [g/km]	$\varphi_{Nox}^{(\#)}$ [g/km]	$\varphi_{PM10}^{(\#)}$ [g/km]
8.69	153	1.2	163.08	0.79	0.43	0.03

(*) Ministero della Transizione Ecologica; (#) ISPRA

Considering the whole dataset, the average number of users per day (*N*) that use the e-bike is about 8, while the average distance *d* is 6.9 km. With these premises, the savings (by year) in fuel consumption and in emissions are reported in Table 3.

Table 3. Savings in fuel consumption and emissions

C [liters]	E_{CO2} [kg/year]	E_{CO} [kg/year]	E_{NOX} [kg/year]	E_{PM10} [kg/year]
1,462.11	2,743.93	13.21	7.16	0.50

Thus, considering a standard business year (260 working days), the carbon dioxide reduction is about 245 kg per person each year (like what was found by McQueen at al., 2020 and Winslott Hiselius and Svensson, 2017).

A close result can be achieved considering a monthly use (Table 4). Figure 6 reports the savings related to CO_2 from September 2020 to April 2021. As in previous consideration, the month of September is out of scale because the other months suffer a lockdown. To figure out these savings, single-user values are reported below the value for user is calculated (orange bars in Figure 6): emerges that the result is congruent whit the literature.

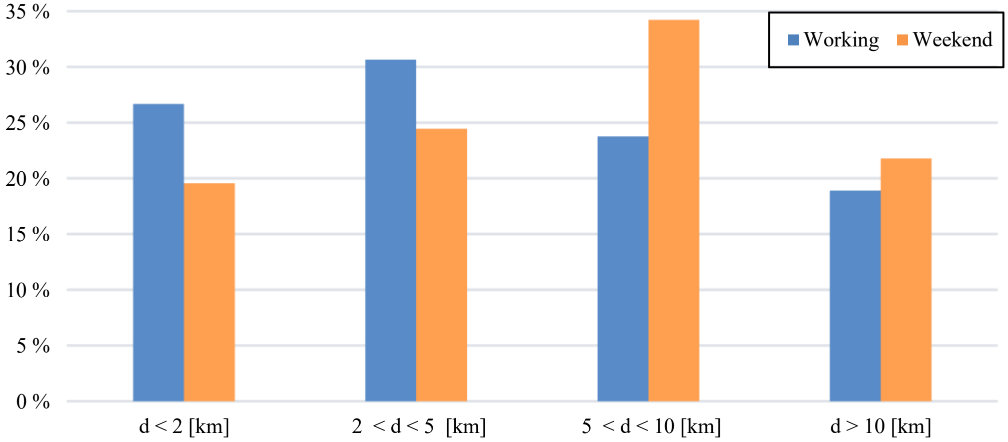


Fig. 5. Kilometres per trip

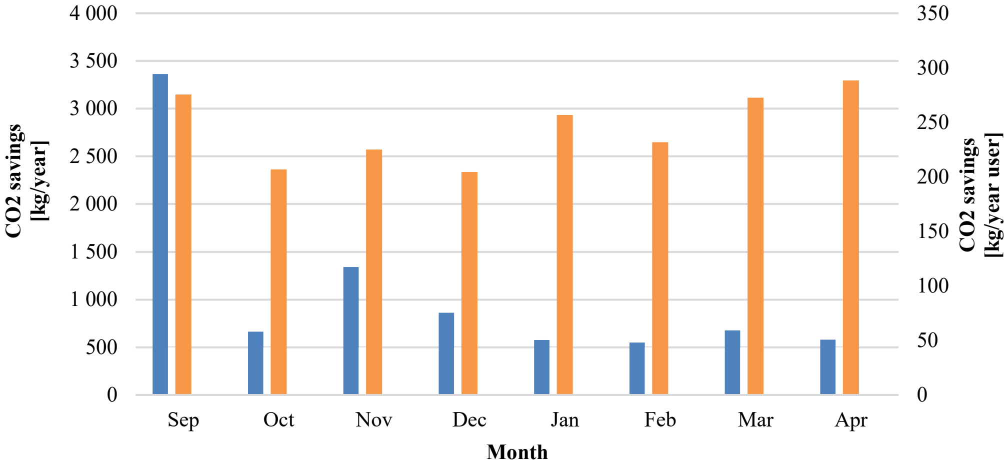


Fig. 6. CO_2 savings

Table 4. Savings in fuel consumption and emissions

Month	C [liters]	E_{CO2} [kg/year]	E_{CO} [kg/year]	E_{NOX} [kg/year]	E_{PM10} [kg/year]
Sep	1,791.47	3,362.04	16.19	8.77	0.61
Oct	352.77	662.03	3.19	1.73	0.12
Nov	713.54	1,339.10	6.45	3.49	0.24
Dec	458.54	860.54	4.14	2.25	0.16
Jan	306.76	575.69	2.77	1.50	0.10
Feb	292.12	548.23	2.64	1.43	0.10
Mar	361.08	677.63	3.26	1.77	0.12
Apr	309.62	581.07	2.80	1.52	0.11

The analyses reported in Sections 4.1 and 4.2 reveal that the users make moderate use of the e-bike. Evidence can be partly explained because the pilot, excluding September, was developed during a lockdown (with a consequent travel reduction). However, it is also necessary to consider how in Messina, 73 % of commuters use cars (ISFORT, 2018): this sets the city in fifth place (with respect to other Italian cities) for using cars in urban travel. Another aspect to consider is the orography of the city, which develops in length and therefore travels inside the urban area can be very long. However, this does not justify excessive use of the car.

At this stage, no demand control policy has been adopted, and users can choose the transport mode freely; thus, the scope of the study consisted in increasing the social awareness toward e bikes-use as an alternative. Limitations emerged in preferences decisions due to the restrictions connected to pandemic evolution, and even more, the limited extension for dedicated cycle line affected choices; anyway, the experiment serves to include the e-bike in the set of alternatives available for the travel.

5. Discussion

The experiment showed that about 15 % of users got used to the electric bike even in activities unrelated to work, thus demonstrating that they appreciate the alternative of transport. Furthermore, during the project, assistance and repair services were provided, giving a powerful incentive for transport reliability among the most frequent users. Indeed, due to improper use and the continuous stresses linked to poor road surface quality, electric bicycles have needed to be repaired for mechanical and electrical problems. In 53 % of cases, the interviewees declared that the assistance service or possibly insurance coverage is, in their opinion, essential to ensure that the electric bike can be considered a valid alternative.

They also affirmed that bike commuting is less stressful than cars due to frequent traffic congestion during peak hours.

To this must also be added a safety gap; indeed, Messina is equipped with only a few kilometres of protected cycle path and many users have highlighted how this limited sense of safety represents today a barrier to active mobility options. Also, security is a crucial point, so dock stations and dedicated parking areas are two of the most recurrent and requested infrastructures that people enlightened as necessary. Anyway, buying an e-bike still does not represent a primary option for the interviewees who affirm how a shared system should result in a more exciting option.

Moreover, a third of the users stated how using the e-bike at least three times a week helps them feel healthy and lets them reduce the assistance level required from the battery, achieving a further environmental goal.

6. Conclusions

This work analysed the data from e-bike use related to a set of citizens participating in a pilot project in Messina. The preliminary results demonstrate that air pollution and fuel consumption could be reduced by providing tactical policies favouring a modal shift from private cars to e-bikes for commuters and students. Furthermore, the analysis of the database (153 working days and 1,357 travels) enlighten that the average travelled distance is 6.9 km (close to other results in the literature) and most of the observed travels (about 31 %) are in the range of 2-5 kilometres. As expected, a gain in emissions and fuel consumption was obtained, and the reduction per year and per person of CO_2 was calculated in 245 kg person each year; the results were consistent/in line with other pilot studies.

Future developments might hit a double path: a survey design, the extension of the pilot to other categories such as students (both from college and university) to collect the data for the estimation of a model able to foresee the users' behaviour in the use of e-bike and the analyse user's willingness in the use of e-bike for crowd-shipping.

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Author contribution

The authors confirm contribution to the paper as follow: supervisors Massimo Di Gangi and Antonio Comi, overview on project by Massimo Di Gangi; analyses and interpretation by Antonio Polimeni and Orlando Marco Belcore, draft manuscript by Antonio Polimeni, reviews by Orlando Marco Belcore and Antonio Comi, final reviews confirmed by all authors.

Declaration

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