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Towards more sustainable urban transportation for NetZero cities: Assessing air quality and risk for e-scooter users using sensor fusion and artificial intelligence

Amin Al-Habaibeh [1*], Matthew Watkins [2], Bubaker Shakmak [1], Maryam Bathaei Javareshk [2] and Seamus Allison [3]

1 Product Innovation Centre, School of Architecture, Design and the Built Environment, Nottingham Trent University, UK.
2 School of Science and Technology, Nottingham Trent University, UK
3 Nottingham Business School, Nottingham Trent University, UK
*Corresponding author: Amin.Al-Habaibeh@ntu.ac.uk

ABSTRACT

The need to develop smart and NetZero cities and reduce carbon emission is driving innovation in cities around the world to use electric transportation technologies. Among that the use of e-scooters. Nottingham (UK) is one of the cities that has an e-scooter scheme where people could rent e-scooters to travel around the city. However, in the current situation, to ensure pedestrian safety e-scooters need to be ridden on the road amongst cars, most of them are fossil fuelled. This gives rise to two potential risks for e-scooter users: the air quality that they breathe and the physical risk of being near cars, where drivers may not be familiar with seeing e-scooters on the road. This paper uses a mixed methods approach by conducting surveys to drivers and e-scooter users, jointly with an experimental work to monitor the journey of e-scooter users combining air quality, GPS data and 360 degrees camera footage to assess the risk to e-scooter riders using sensor fusion and artificial intelligence. The results indicate that the suggested novel methodology is effective in understanding the current limitations and the potential air quality and physical risks to e-scooter users.

Keywords: Air Quality, Micro-mobility, Artificial Intelligence, Smart Cities, Transportation, Net-Zero Cities.

1. INTRODUCTION

Air pollution is a significant life-threatening issue in numerous countries worldwide, posing risks to public health and the environment [1]. The World Health Organization identifies road transport as a significant source of harmful air pollution, along with vehicles, power generation, heating systems, industry, and agriculture/waste incineration [2]. Over the past few years, there has been a world-wide demand for the use of electric scooters as micro-mobility devices. Electric scooters are eco- friendly and offer solutions to a wide range of transport policy goals such as reducing air and noise pollution. Since their first introduction in 2017, many countries in the US, Europe and large metropolitan cities in New Zealand and Singapore have widely started using electric scooters to make benefits to the environment and public transport system [3]. Electric scooters (e-scooters) are a new transportation option which can rapidly change the travel system in urban environments. In March 2019, the UK government identified new strategies for greenhouse gas emission saving and transport innovation [4]. The rental of e-scooters was permitted through pilot schemes in 32 British regions from July 2020 [5], however under existing legislation privately owned scooters are still illegal for use on public roads, cycle lanes and pavements being legally permitted for use on privately owned land in the UK only [6]. In addition, e-scooters riders must be at least 18 years old and hold a driving license, whilst helmets are recommended but not legally required. E-scooters riders who violate these rules face the prospect of a £300 fixed penalty notice and six points on their driving license if stopped by police, with their e-scooter potentially impounded.

However, regulations governing the use of e-scooters vary between countries. For instance, in Italy, rented electric scooters are allowed on bike lanes and streets but not on pavements and riders must be at least 14 years old, with helmets recommended but not required. In San Francisco, California, riding e-scooters on pavements is also prohibited, and riders must have a permit and are required to wear helmets [7]. E-scooter regulations also vary by province and municipality in

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Canada. For instance, in Toronto, Ontario, rented e-scooters are allowed on roads, bike lanes, and multi-use paths but not on pavements. In addition, riders must be at least 16 years old, and helmets are required for all riders under 18 years old. Similarly in Vancouver, British Columbia, rented electric scooters are allowed on bike lanes and roads but helmets are required for all riders [7].

Previous research shows that around 65% of current and past e-scooter users in the US considered an e-scooter as a convenient device to ride and reported feeling 'somewhat' or 'very' safe while riding this device [8]. However, this study also revealed that the younger generation considered using e-scooters impractical for long distances and difficult to use in hot weather conditions. Further research carried by Department for Transport [6] investigated the public awareness on e-scooters use in the UK. The results showed that around 50% of respondents had some degree of knowledge on how to use e-scooters and this was higher among males, younger participants, those living in urban areas and from higher social grades. The findings also revealed that the usage of e-scooters was relatively low in the UK with only 7% of participants stated that they had ever used e-scooters and only 18% of this population reporting ownership of an e-scooter [6].

There are road sharing challenges facing cities that would like to implement sustainable transportation such as e-scooters, see Figure 1.

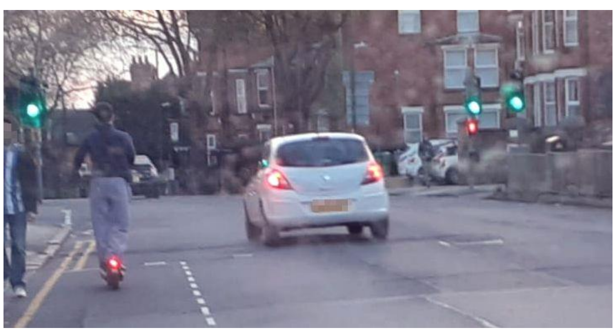

Fig. 1. E-scooter user on the road; note the low visibility clothes and the low level of the e-scooter's rear light.

There is a growing popularity of e-scooters, but unfortunately, the current research on safety of electric scooters and air pollution is very limited. Most e-scooters studies neglect consideration of the impact on the environment and health in terms of air pollution exposure [9]. There also haven't been many experimental studies to consider individual users and non-user perspectives on the benefits and barriers of using e-scooters compared to other transport modes. Furthermore, there is a need for a deeper comprehension of e-scooter safety and their potential roles in advancing zero-carbon initiatives and sustainability. This paper aims to address this gap by collecting information on the use and perceptions of e-scooters. Including the road safety and air quality impacts for vulnerable road users (e-scooter users, cyclists, and pedestrians) during their commutes in urban centers across the UK, EU, USA, and Canada. Additionally, the study aims to explore the perceptions of safety regarding electric scooters among drivers in the UK.

2. METHODOLOGY

The research study considers a mixed methods approach comprising of two separate quantitative and qualitative surveys and experimental air quality data collection and analysis.

2.1 Surveys

Two online surveys (E-scooter survey, Driver survey) using Qualtrics were created and distributed through social media platforms including Reddit, Prolific, LinkedIn and through the researchers 'direct contact' using a snowball effect. The primary objective of the first questionnaire was to gather perspectives from the public in various countries (UK, EU, USA, and Canada) on the use of e-scooters in comparison to other transportation modes, as well as to assess their perceptions of e-scooter safety. The second questionnaire exclusively targeted the car driver population aiming to explore their viewpoints regarding e-scooters. Both questionnaires employed a mixed-methods approach, incorporating multiple-choice quantitative questions and open-text qualitative questions.

2.2 Air Pollution and Road Safety Monitoring

Experimental work to collect real time air quality and road safety data, utilized air pollution monitoring of PM 2.5 and PM 10 particulates, a GoPro camera, a 360 camera and GPS data. This allows to capture location, air quality and proximity to cars and road users as shown in Figure 2.

Fig. 2. The sensor fusion setup for e-scooter users;
includes a GoPro camera, PM 2.5 and PM 10 particulates data logger, GPS logger and 360 degrees camera.

Seven e-scooter users were asked to wear a helmet fitted with a 360 camera and carry a rucksack containing the Air pollution monitor and data logger recording air pollution levels at 1-minute intervals, a Go Pro camera, and a GPS logging device. A sensor head specifically designed for monitoring microparticles has been selected.

3. RESULTS

3.1 E-Scooter Survey

N = 801 respondents completed the e-scooter survey, comprising 373 males (46.6%) and 415 females (51.8%). UK residents had the highest response (48.94%), with additional responses from the EU (24.97%), USA (12.73%), and Canada (13.36%). The age of the respondents ranged from 18 to 77 years, (*Mean*=35.24, *SD*=11.66). In terms of employment status, the breakdown was as follows: full-time (56.7%), part-time (14.7%), retired (2.9%), not working (8.4%), students (12.9%), prefer not to say (1.2%), and other (3.2%). The "other" category encompassed responses such as those who were both students and working simultaneously, self-employed individuals, stay at home parents, family carers, individuals on maternity leave, those on sick leave, and housekeepers.

Respondents were asked questions relating to both bicycle use and e-scooter use to permit comparison and there were notable differences in their perspectives, preferences, and perceptions. For bicycle usage, 61% of participants had never used them for commuting, while less than 10% stated they always or usually use bicycles for commuting. In contrast, a significant portion of participants (47.3%) had never used e-scooters for commuting, whilst 7.5% and 9.3% always or usually used e-scooters for commuting, respectively.

In terms of leisure use, 5% of participants always used bicycles, whereas 32.2% sometimes did, and 13.4% usually used them for leisure. Conversely, with e-scooters, 7.5% consistently used them for leisure, 14.6% usually did, while 17.3% had never used them for leisure activities. Considering perceived safety, 35.3% felt a bit unsafe while riding bicycles, and 31% felt quite safe, whilst, for e-scooters, 36.7% considered them quite safe, but 39.4% found them a bit unsafe as shown in figure 3.

Furthermore, for commuting, most participants (67.9%) believed cyclists should wear helmets all the time, compared 75.5% for e-scooters. A Chi-Square test was conducted to test for an association between the mode of transportation (bicycle vs. e-scooter) and opinions on helmet usage. The results showed that the differences in opinions on helmet usage between bicycle and e-scooter users are statistically significant (X^2 (4) = 664.50, P< 0.05).

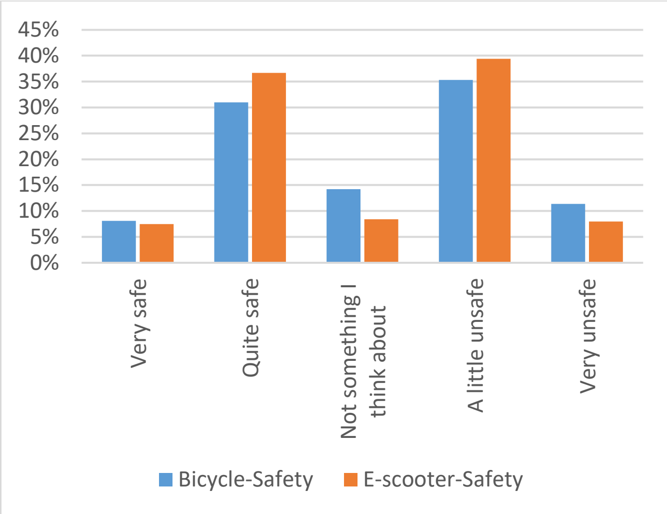

Fig. 3. Bicycle vs e-scooter safety.

When participants were questioned about the potential safety risk of e-scooters on pavements for pedestrians, a significant proportion, 43.7% expressed strong agreement and 34.2% of participants agreed they are a hazard. Furthermore, a substantial 34.5% strongly agreed that e-scooters parked on sidewalks obstruct pedestrians' paths, with an additional 33.1% in agreement. Over half respondents agreed with the statement that e-scooter users ride dangerously and pose risk of injury to themselves or others. With 31.8% of participants agreeing and 19.9% of participants strongly agreeing with this statement.

Participants generally expressed agreement on a variety of e-scooter risks, with 38.2% agreeing that e-scooters are risky, 42.3% agreeing that they pose hazards to visually impaired pedestrians, and 38.3% agreeing that they can be a hazard for hearing-impaired pedestrians.

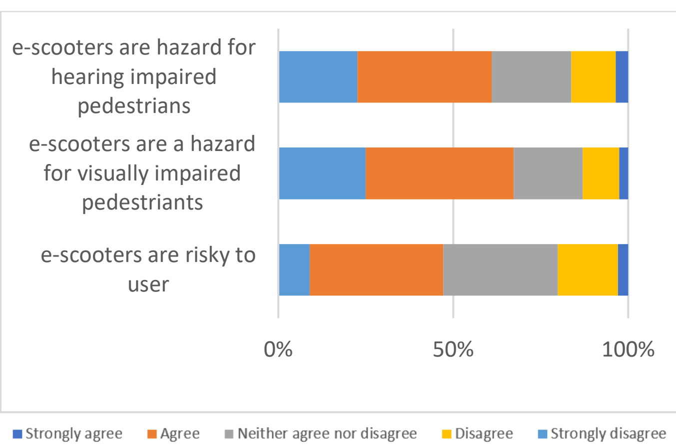

Fig. 4. Participant agreement on e-scooter risks.

Participants' perspectives on bicycle and e-scooter infrastructure revealed distinct challenges and concerns. Regarding bicycles, 26.6% acknowledged suitable infrastructure in their cities, but 22.3% reported inadequate facilities, citing infrastructure quality, the need for expansion and improvement, safety issues, and the importance of additional parking and storage. For example, a participant mentioned:

"Not very many dedicated cycle lanes, lanes are very narrow in some place, it is difficult as a driver to safely overtake cyclists."

For e-scooters, 33.1% stated the absence of appropriate infrastructure, while 21.3% believed there is suitable infrastructure. Safety concerns included rider awareness, inadequate infrastructure, traffic, and unsafe riding practices. The mixing of e-scooters with pedestrians on sidewalks raised safety issues, as does their use on roads and cycle lanes without dedicated spaces. Parking challenges and a lack of regulations and education further compound the issue. Participants also highlighted design-related concerns like low visibility at night. For example, a participant mentioned:

"The e scooters need better lights; it is hard for me to see riders while driving on a universities poorly lit campus at night".

Concerning the impact of improved infrastructure for e-scooters on individual preference for use, 25% of participants expressed their inclination to start using e-scooters or increase their usage if infrastructure were improved.

Inquiring about air quality awareness, 41.7% of participants described their area as rarely polluted, while 35.5% considered their area polluted. Only 4.7% found their surroundings very polluted, but surprisingly 12.5% believed their city was entirely free from pollution and 5.6% admitted to being unaware of their city's air pollution condition. Participants were also asked about the extent of air pollution's impact on them, 3% said it always affects them, while 21.7% claimed it never does. Furthermore, 38.5% reported rare effects, 28.2% occasional impacts, and 8.6% usual experiences of air pollution's effects.

Participants were further prompted about the effects of air pollution on their lives, including breathing difficulties, reduced outdoor activity, eye/nose/throat irritation, skin issues, relocation considerations, asthma, visibility problems, and long-term health concerns. The results showed 15.1% experienced breathing difficulties, 17.5% reduced outdoor activity, 31.3% eye/nose/throat irritation, 10% skin problems, 17.1% considered relocating, 9.4% had asthma incidents, 7.7% faced visibility issues, and 39.2% worried about long-term health effects. Participants also mentioned odors, headaches, migraines, hair loss, and allergic rhinitis as additional air pollution impacts. This study investigated participants' views on electric scooters as a sustainable transport option. Among the 801 participants, 56.2% responded affirmatively (yes), 33.6% expressed uncertainty (maybe), and 10.2% responded negatively (no). Furthermore, participants generally agreed that e-scooters were beneficial for the environment, with 17% strongly agreeing and 48.4% in agreement. Although in reality Life Cycle Analysis studies find the opposite to be the case [10].

In relation to the potential for e-scooters to improve air quality, 22.8% of participants strongly agreed and 52.3% of participants agreed with the statement. In addition, 50.4% and 19.5% of participants agreed and strongly agreed that E-scooters can ease the congestion.

Regarding the usefulness of e-scooters as mobility options, the majority of participants (56.8%) agreed that e-scooters provide useful mobility options whilst 25% of participants expressed strong agreement with this statement. When participants were asked whether E-scooters would help improve balance and co-ordination a notable percentage of 38.6% expressed agreement with this statement and 13% strongly agreed.

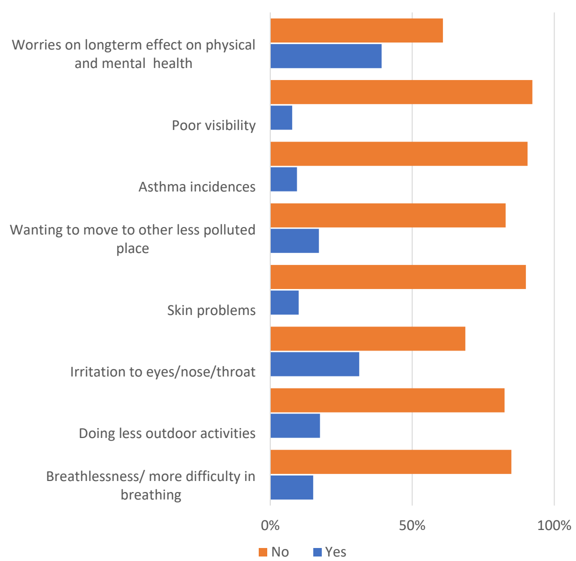

Fig. 5. Effects of air pollution on health and well-being.

In terms of the potential for e-scooters to replace some taxi/Uber/Lyft rides, 19.4% of participants strongly acknowledged the possibility and a further 39.2% of participants agreed with this notion.

3.2 Driver Survey

The driver survey was conducted with UK drivers only and had N = 92 respondents, 66.3% as male, 31.5% as female and 1.1% "Other," and a further 1.1% who chose not to disclose their gender. For age distribution, the largest group was 31-40 (28.3%), followed by 26-30 (19.6%), 41-50 (19.6%), 18-25 (15.2%), 51-60 (12%), and those 61 and older (3.3%). Almost all respondents (98.9%) reported being regular drivers. The majority (64.1%) of respondents had held a full driving license for over 10 years, 14.1% for 2 years or less, 9% for 3-6 years and 12% for 7-10 years.

Participants' opinions on e-scooter visibility on roads varied, with 27.2% agreeing and 3.3% strongly agreeing that e-scooters are fully visible on roads, whilst 12% were neutral, 39.1% disagreed and 18.5% strongly disagreed. Participants were asked to assess whether e-scooter users are taking adequate safety measures. Only 2.2% fully agreed, while 51.1% strongly disagreed, 26.1% disagreed, 18.5% were neutral, and 2.2% strongly agreed. When it came to perceiving e-scooters as potential hazards for car drivers and other road users, 33.7% agreed, 35.9% strongly agreed, 7.6% disagreed, 8.7% strongly disagreed, and 14.1% were neutral. Lastly, in terms of e-scooters being a convenient mode of transportation that can reduce traffic congestion and air pollution, 34.8% agreed, 30.0% strongly agreed, 9.8% disagreed, 5.4% strongly disagreed, and 19.6% were neutral.

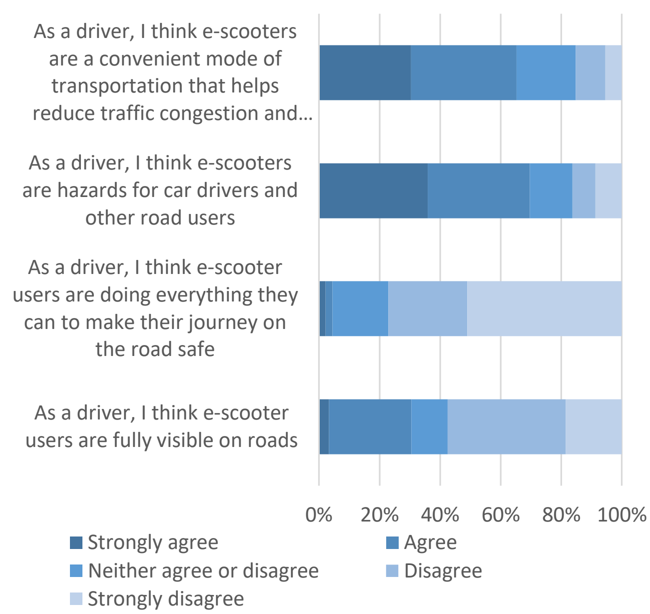

Fig. 6. Key findings on e-Scooter perceptions among drivers.

Furthermore, driver general comments revealed important findings: drivers are worried about e-scooter safety, want clearer rules and training for e-scooter users, suggest better visibility, call for improved infrastructure, have mixed feelings about e-scooters in cities, and have different opinions on whether to ban or allow them. For instance, a participant mentioned:

"Scooter drivers should have some form of road teaching if they have to drive on the road. But the scooter company doesn't provide this! Yet expect them not to drive on the pavement! E-scooters are a great concept but poorly executed".

Or the other participant mentioned:

"Better bike infrastructure would provide a safer space for e-scooter users and reduce incidence of collision with cars. I think most e-scooter riders try their best to be safe but have limited space to move freely in cities safely".

3.3 Air Pollution

Figure 7 presents an example of the air pollution monitoring conducted during the study. The PM10 readings are found to be higher than the PM2.5. The Air Quality Standards Regulations 2010 require that concentrations of PM in the UK must not exceed: an annual average of 40 µg/m3 for PM10; and an annual average of 20 µg/m3 for PM2.5. The Environmental Targets (Fine Particulate Matter) (England) Regulations 2023 require that in England by the end of 2040: An annual average of 10 µg/m3 for PM2.5 is not exceeded at any monitoring station. And population exposure to PM2.5 is at least 35% less than in 2018. We have found that the readings in the sample of Figure 3 are within the expected limits.

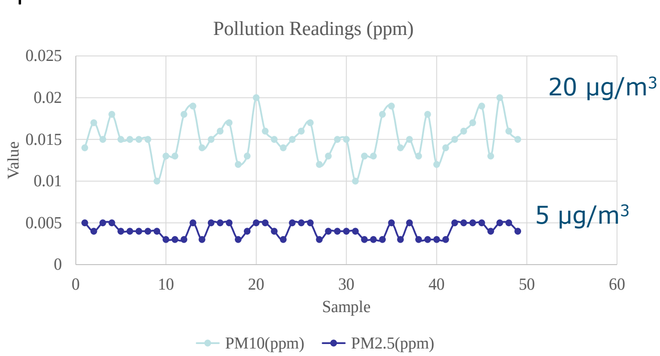

Fig. 7. Air quality monitoring (one-minute sampling rate).

Figure 8 presents an example of the 360 degrees camera image, which displays all 4 sides around an e-scooter user when attached to the helmet. This data was analysed by artificial intelligence through MATLAB to count the number of cars per minute that the e-scooter user passes by, whilst the GPS module determined the location and the sensor measured air quality.

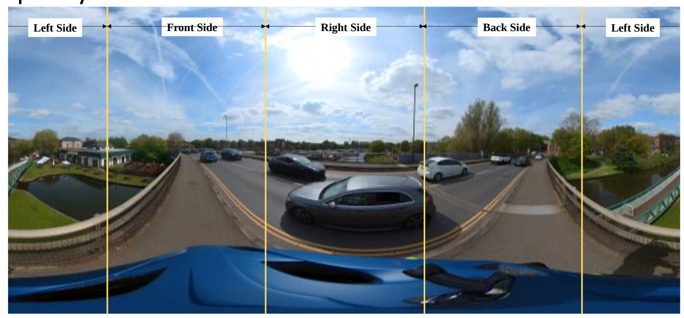

Fig. 8. 360 degrees image which shows the four sides in one image.

Figure 9 presents an air pollution map of all e-scooter users in the test for PM10 and PM2.5, indicating the city centre has higher air quality issues, compared to areas away from the centre.

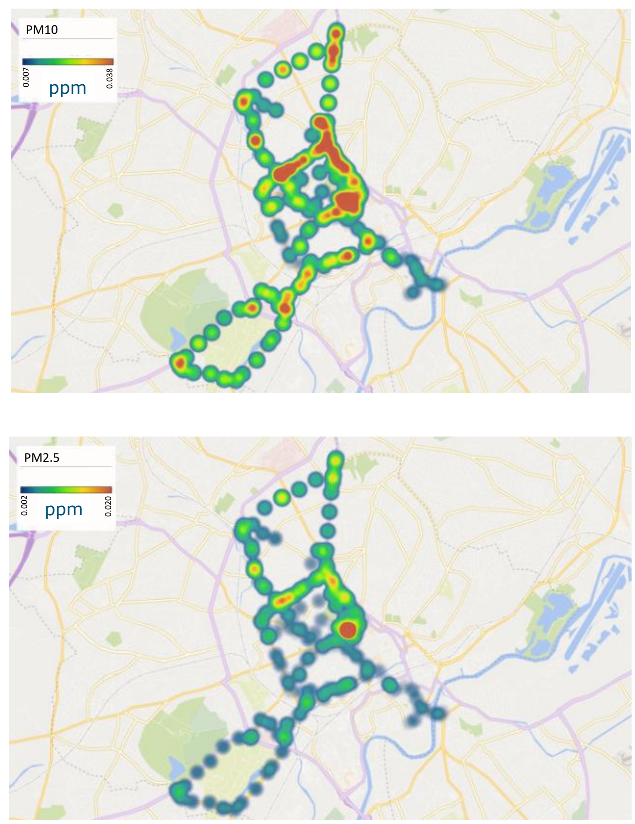

Fig. 9. Air pollution map as experienced by e-scooter users (PM10 and PM2.5 respectively).

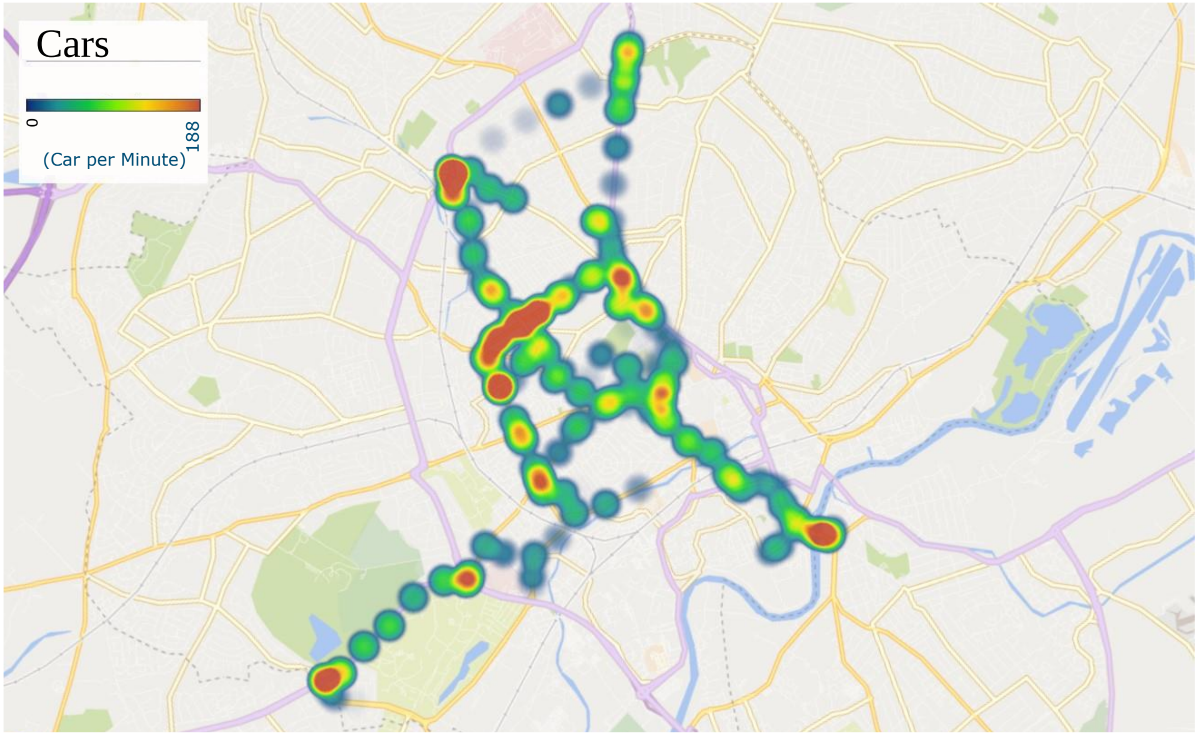

Fig. 10. Number of cars passed by the e-scooter users (per minute).

Figure 10 presents the number of cars (N) that the e-scooter users have passed by during their journeys. Figure 11 presents the relationship between air quality and the number of cars where there is a clear association.

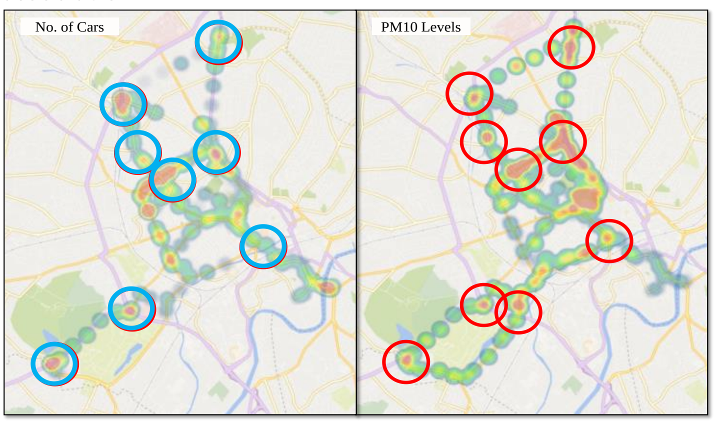

Fig. 11. Relationship between number of cars and air pollution (PM10).

4. CONCLUSION

There has been significant questions about the safety of e-sccoter users in cities due to their close proximity from cars, their low visibility and the potential poor air quality the users breath around fossil fuel vehicles. A mixed approach has been used in this paper to capture information about e-scooter use as a case study. The results show that both e-scooter users and drivers view the concept favourably but differ on the reality with both perceiving issues with infrastructure and road sharing which can lead to greater concerns around safety of both riders and pedestrians. Both the perceptions of air pollution and the e-scooter impact on the environment are more favourable from the user's perspective than reality when measured. A novel approach has been implemented to allow the monitoring and prediction of air quality based on GPS data, air quality monitoring, existence of cars and the level of green areas.

AI (Neural networks) techniques are utilised to estimate the number of cars using image processing. The results indicate that cars and green areas play an important role in increasing or decreasing air pollution levels respectively. It has been found essential, in order to understand the air quality during commuting, to fully understand the variables affecting the process. The variables include the time of travel, proximity from cars and proximity from green areas. Each sensor has its own limitations, and the integration of data (sensor fusion) is needed. Artificial Intelligence combined with sensor fusion can provide an enhanced analysis of complex data.

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