An Estimation of Emission Patterns from Vehicle Traffic Highlighting Decarbonisation Effects from Increased e-fleet in Areas Surrounding the City of Rzeszow (Poland)

Tiziana Campisi[1](✉), Maksymilian Mądziel[2], Andreas Nikiforiadis[3], Socrates Basbas[3], and Giovanni Tesoriere[1]

[1] Faculty of Engineering and Architecture, University of Enna Kore, Cittadella Universitaria, 94100 Enna, Italy
tiziana.campisi@unikore.it

[2] Faculty of Mechanical Engineering and Aeronautics, Rzeszow University of Technology, 35-959 Rzeszow, Poland

[3] Department of Transportation and Hydraulic Engineering, School of Rural and Surveying Engineering, Faculty of Engineering, Aristotle University of Thessaloniki, 54124 Thessaloniki, Greece

Abstract. After several months of lockdown and the freezing of many human activities, Europe has entered phase III of the management of the COVID19 emergency. The pandemic made necessary to give great attention in the economic recession and also to give emphasis on the decarbonisation of our economy. While the European Commission reaffirms its determination to move forward with the European Green Deal and announces a green recovery plan, many governments are rapidly putting in place public stimulus programmes to boost the economy and restore jobs. After years of rising CO_2 emissions from road transport and the lack of investment in clean technologies, in the early 2020s an unprecedented growth in sales of zero and low emission cars was observed in the EU. The three main pillars for the success of e-mobility are the spread of electric vehicles, the carbon-neutral production processes and the use of energy from renewable sources. The present work shows the usefulness of traffic simulation tools for the comparison of existing and future scenarios, paying particular attention to the variation of the percentage of electric vehicles in the fleet. More specifically, a specific emission model is being used in the case of a roundabout in the city of Rzeszow, Poland and the results underline the importance of preventive analysis for the implementation of optimal transport decarbonisation strategies, as well as they lay the groundwork for future research steps.

Keywords: Electric vehicles · Decarbonisation strategies · Emission models · Traffic simulation · Roundabout

O. Gervasi et al. (Eds.): ICCSA 2021, LNCS 12953, pp. 683–698, 2021.
https://doi.org/10.1007/978-3-030-86976-2_47

1 Introduction

The European Union is implementing a series of strategies to achieve a reduction in pollutant emissions from vehicle traffic by 2030 and 2050. The fact that the European Union highly prioritizes the significant reduction of CO_2 emissions is being already understood with the 2011 White Paper on Transport [1] and it became even clearer with the recent European Green Deal [2]. In the epicentre of the activities for achieving this important objective is the promotion of electromobility. However, the effective reduction of emissions requires the utilization of renewable energy sources for vehicles' charging [3].

The compatibility of electric vehicles with renewable energy sources has motivated many businesses, governments and non-governmental organisations to introduce electric vehicles in their fleets to drastically reduce oil consumption, reduce carbon pollution, eliminate local air pollution and stimulate economic development. Long-term planning scenarios indicate that the global vehicle fleet needs to be almost entirely made up of electric vehicles, powered mostly by renewable sources, for avoiding the worst-case scenarios of the global climate change in 2050.

The present paper aims to quantify the benefits of introducing electric vehicles, by applying simulation tools and emission models. Through this quantification, it is sought to understand the potential of electromobility for contributing in the environmental sustainability of the road transport sector.

The case study examined in this paper refers to a roundabout which is a very effective traffic management "tool" used worldwide to achieve a satisfactory level of service for motorized traffic and to secure a high level of road safety for vulnerable road users [4–6]. In addition, roundabouts have a significant effect in the environmental conditions since they are expected to reduce air pollutants like CO_2 and noise emissions [7, 8].

Another important aspect is the forthcoming introduction of autonomous and connected vehicles in the daily operation of roundabouts where the use of algorithms and simulation techniques is essential to assess the impact of the new technologies [9, 10]. For all the above-mentioned reasons, it is considered very interesting to test the simulation scenarios concerning the e-fleet in a roundabout which is a crucial element of the road network and will continue to be in the future.

2 The Spread of e-mobility in Europe

In recent decades, various regulations have been implemented for setting restrictions regarding the use of high-polluting vehicles. The regulations concern both technological and taxation aspects.

The efforts for limiting the use of high-polluting vehicles also include the introduction of electric vehicles, which do not directly emit air pollutants or CO_2. As of 2010 a number of actions have been implemented to improve the environmental performance of vehicle fleets and it is anticipated that the electric vehicles market will rise due to European CO_2 targets. These targets have motivated the formation of national plans that ban the sale of new cars with internal combustion engines, for example in Norway, the Netherlands, Ireland, Slovenia, France and the UK [11–13]. The increase of new zero-emission vehicles on the market will also lead to a greater availability of these vehicles to second-hand vehicle buyers.

Despite the goals that European Union has set for the reduction of emissions coming from the transport sector, it has been observed that significant differences exist between the European regions. More specifically, Northern, Central and Western European countries have the most environmentally friendly vehicle fleets, with less CO_2 emissions on average. On the other hand, the vehicles in the South-Eastern, Central-Eastern and Southern European countries emit greater CO_2 volumes on average.

Vehicle trade flows also follow different patterns among the different European regions. For instance, the Northern and Central European countries export far more used vehicles than they import; since the total number of vehicles is not being shrinked, it becomes clear that the difference is being covered by new vehicles. On the contrary, the South-East and the Central-East countries are the main importers and, in many cases, they import vehicles with relatively high air pollutants and CO_2 emissions.

One of the most influential factors for these differences between the European regions is the household income, which differs significantly and determines to a large extent the penetration rate of electric vehicles [14].

Except for the income, national regulations and taxation systems have a significant role to play in the motivation of users for purchasing a low-emission vehicle or even an electric. However, in countries such as Serbia, Bosnia-Herzegovina and Hungary, bans on the import of old vehicles or on vehicles with low European emission standards, did not led to the import of higher-value vehicles. These countries in particular import vehicles that have a low price and also average emissions (e.g. due to high mileage travelled or technological inefficiencies). However, further research is needed to better understand the impact of various import bans on the vehicle fleet and its environmental-friendliness.

The penetration of electric vehicles in the European market is well defined by Fig. 1. It can be clearly seen that Norway and Northern European countries in general have the highest rates (15–25% or even more), while very low penetration rates of around 1–3% are observed in countries such as Poland.

The diffusion of shared mobility with electric vehicles is accompanied by various campaigns that raise awareness [15] and by strategies that encourage the use of electric vehicles for both taxis [16, 17] and DRT [18–20].

2.1 The development of electric mobility in Poland.

Poland is one of the countries with the highest levels of pollution from road traffic [21, 22]. It is currently characterized by a national traffic composition defined on Table 1 considering different fuelling types per vehicle category in Poland in 2019–2020.

The Polish Ministry of Energy proposed in its electromobility development plan, which was adopted in September 2016, an ambitious target to see 1 million electric vehicles on Polish roads by the end of 2025. This programme is divided into two independent components: one aiming at the development and production of electric buses and one that focuses on the design and production of a Polish electric car. Moreover, the Polish Ministry plans to create a system of incentives in order to promote electric vehicles at this level.

In 2018, laws were adopted in favour of electromobility and alternative fuels. A number of actions were implemented regarding the facilitation of electric mobility, including the formation of a framework for basic infrastructure for alternative fuels (electricity,

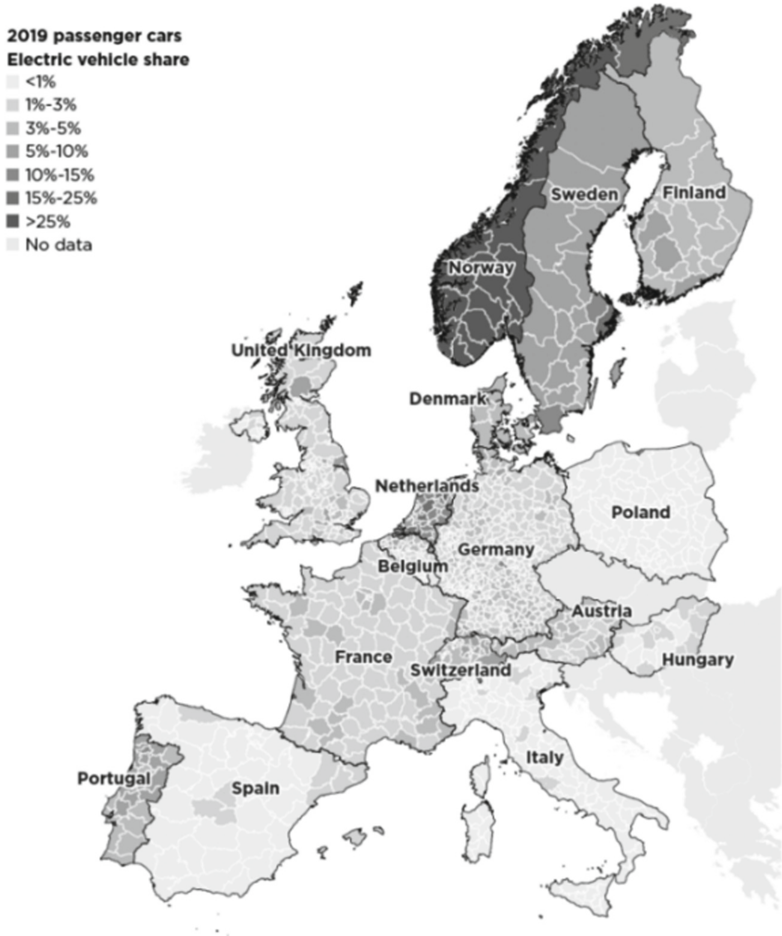

Fig. 1. Electric share of 2019 new passenger car registration in 16 European countries (source: https://theicct.org/publications/european-electric-vehicle-factbook-20192020).

Table 1. Distribution of different fueling vehicle type in Poland.

Vehicle category	Diesel	petrol (including bi-fuel)
Passenger cars	60,5%	39,5%
Commercial vehicles	86,0%	14,0%
Trucks	99,7%	0,2%
Coaches	99,4%	0,6%
Public transport	100,0%	0,0%
Buses (Light commercial vehicles)	100,0%	0,0%

LNG, CNG and hydrogen). Additional measures that have been implemented to promote electric vehicles in Poland are the allowance of installing charging stations without building permits and the establishment of a law that exempts suppliers from the obligation to obtain a licence for electricity trading in the case of charging services. Also, fiscal benefits are in place with exemption from excise duty for electric and hydrogen vehicles.

From an infrastructural point of view, parking spaces dedicated to electric vehicles during charging have been designed and implemented in paid parking zones. Polish legislation also indicates a minimum number of charging points to be installed per municipality. In addition, electric vehicles will be allowed in bus lanes until 1 January 2026. A main challenge is also the installation of public charging stations along TEN-T roads.

Recent surveys show that between 28% and 45% of citizens and businesses in Poland would consider buying an electric car and consumers have a generally positive opinion of electric vehicles, but they expect that the purchase of electric vehicles should be supported. [23, 24]. At the same time, registrations of new electric cars in Poland have shown a positive trend. In 2019, a total of about 2,600 new electric cars were registered in Poland, a share of 0.5%. In July 2020, the number of electric passenger cars in Poland amounted to over 13 thousand, an increase of 12% since May 2020. The battery electric vehicles (BEV) accounted for 35–38% of the electric cars market as of July 2020 [22, 25] as it is presented in Fig. 2.

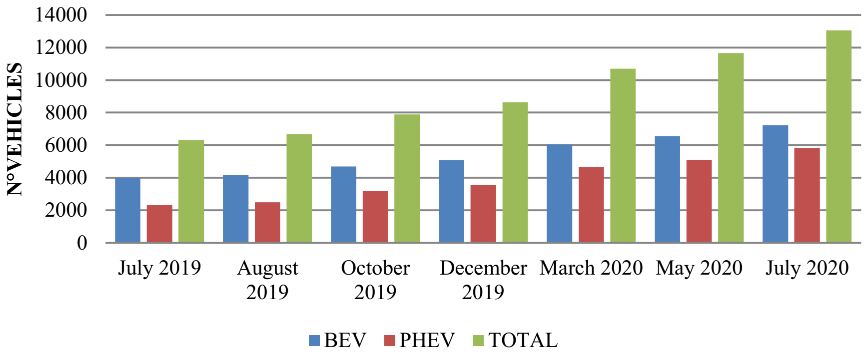

Fig. 2. Polish trend related to different type of vehicle.

Poland has the largest concentration of battery production plants for electric vehicles in Europe. Several strategies are available in the literature to study the demand and supply of transport with particular reference to electric mobility. In order to understand which strategies can be put in place to improve electric mobility, several investigative steps are necessary: on the one hand, the distribution of surveys to the population could highlight some criticalities related to the use of electric vehicles and difficulties in travel habits; on the other hand, an evaluation with simulation software could highlight some criticalities related to the types of infrastructure currently present in the area.

After a brief analysis of the literature and of the trends in electric mobility in Poland, this manuscript focused on the analysis of a roundabout intersection with an average high traffic flow due to the presence of numerous commercial and other activities and on the possibility of comparing traffic scenarios with constant increases in electric vehicles through the use of traffic microsimulation as a preventive evaluation and possible mitigation tool of environmental impacts. Several traffic scenarios were compared and the results yielded useful conclusions for the implementation of decarbonisation policies in the area examined.

3 Methodology

3.1 Microsimulation Approach

The comparison of multiple hypothetical scenarios was possible through a microsimulation evaluation. Microsimulation tools allow the assessment of traffic scenarios, which include fluctuations of the vehicle's composition, and changes in geometric and functional characteristics of the infrastructure [26]. There are numerous tools that allow the surrogate evaluation of safety parameters [27], but also the level of service assessment for vehicular flows or even pedestrian flows [28, 29]. Moreover, they can provide an estimation regarding the produced emissions [30, 31]. The study was carried out using the VISSIM software and the RoundaboutEM emission model [32, 33], comparing different layouts with the same intersection geometry but with different percentages of electric vehicles in the fleet, and estimating the CO_2 concentrations that are being produced. The selected area is located in the northern part of the city of Rzeszow, which is in the south-eastern part of Poland. In particular, a two-lane roundabout intersection on the ring road was identified, characterised by medium-intense traffic linked to the various activities in the vicinity of the investigated area.

3.2 Case Study Analysis

Congestion phenomena that are being caused by vehicle traffic have started playing a significant role in the area connected to the city of Rzeszow. One of the main reasons for the increase in traffic congestion in Rzeszow is the fast growth of the city area (since 2006, the city has expanded its administrative boundaries six times) and the relocation of inhabitants from the city centre to the suburbs.

As a result, the increasing number of people working in Rzeszow are forced to commute every day, which results in increased traffic and leads to traffic congestion [32]. Moreover, there are no ring roads (north-south) and motorways (north-south) and comparing with other cities in Poland, Rzeszow has a very low share of bicycles.

Thus, further decisive action is needed from the municipal authorities to promote cycling. The investments in bicycle lanes [33, 34], that were implemented in recent years, were not supplemented by appropriate actions to change mobility habits. On the public transport side, the increase in the number of passengers has been greater than the growth of the city's population in recent years. This was achieved largely due to measures taken by the city's authorities to reduce public transport journey times and make traffic flow smoother in congested areas.

Improving the energy efficiency of public transport, the negative effects on the environment can be reduced, especially with regard to the emission of greenhouse gases and other toxic substances. The introduction of electric buses on these routes would lead to a decrease in fuel consumption and it would limit the emission of harmful substances into the atmosphere.

The present study shows a comparison of scenarios (actual and theoretical) in one of the roundabouts located in the city of Rzeszow, in the East part of city like, as it shown in Fig. 3.

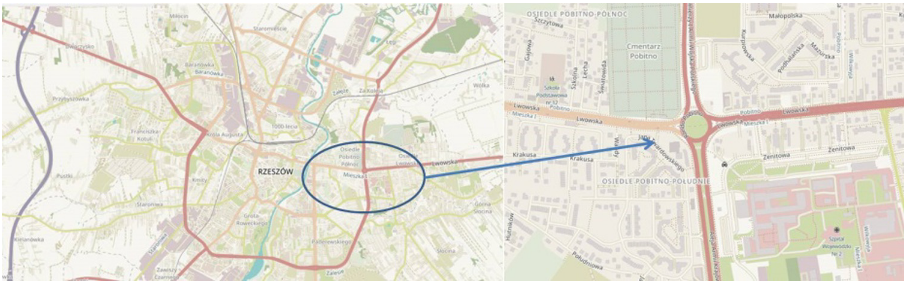

Fig. 3. Location of the examined roundabout (source: https://www.openstreetmap.org/#map=15/50.0360/22.0211&layers=T).

This area was selected because it is characterised by a high level of vehicle traffic and the presence of various commercial and other activities in the proximity. An assessment of the emissions generated by an increasing percentage of light vehicles, starting from the composition of the local fleet, has allowed us to understand the benefits of the spread of electric mobility in terms of the concentration of pollutants. The roundabout intersection was initially analysed in terms of functional geometry and was reproduced by defining arcs using VISSIM software. The city of Rzeszow bears witnesses to practically all unfavourable effects of urban development related to the functioning of transport. The increase in the number of vehicles and traffic intensity contributes to road congestion and higher journey times [26]. In particular a functioning roundabout with four arms and double lanes was selected like described on Fig. 4. The daily traffic is about 1000 veh/h during the peak hour 08:00–09:00 in the morning of weekdays. The roundabout is named Rond Pobitno and it connects an urban with a national road. The intersection is characterized by the presence on both directions of cycle paths. The secondary direction is defined by ul. Lwowska (East to West and vice versa), while the main direction is defined in the south part by al. Armii Krajowej and in the northern part by al. Żółnierzy i Armii Wojska Polskiego (North to South and vice versa) (see Fig. 4).

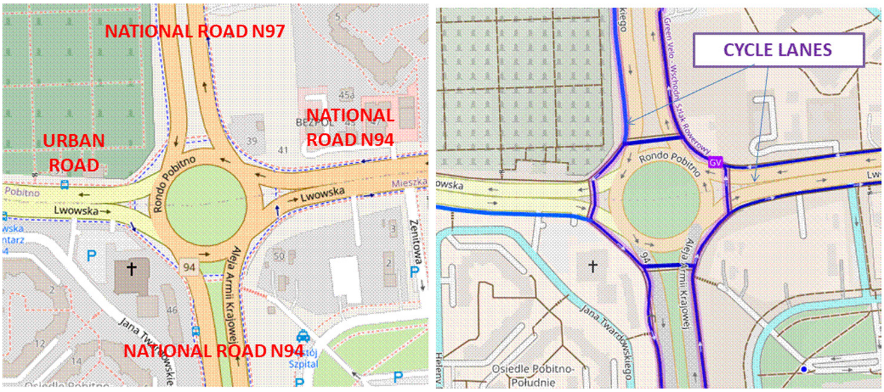

Fig. 4. Roads classification and bike lane (on blue) location. (Color figure online)

The outer diameter of the roundabout is 84 m. The road width in inlets and outlets is 4.15 m and, in the roundabout, it is 4.28 m. The roundabout is located next to supermarkets, a hospital and actually enables to enter the city from suburban areas, while it is also a crossing node of national roads. Due to its importance, the specific roundabout was chosen for the research. Figure 5 presents the real and the simulated roundabout.

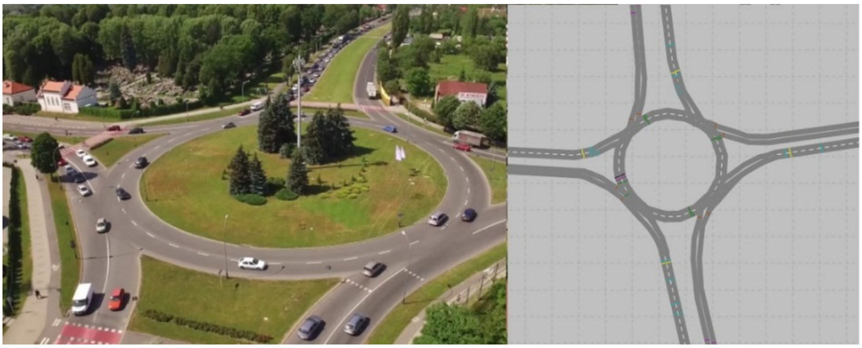

Fig. 5. The real and the simulated geometrical scheme of the analyzed roundabout.

Five scenarios have been selected, one of which is the current scenario and the others assume an increase of 5–10–15 and 30% in the share of electric vehicles. These scenarios do not envisage 100% of electric vehicles on the road, as reaching this figure is a long way off. However, the scenarios are quite consistent with European strategies, with an action horizon of the next few decades. In particular these scenarios were selected after considering the European strategies described in Table 2.

Table 2. Target for inclusion of electric vehicles in European strategies

	A	B	C	D	E	F	G	H
2025	50%	15%	20%	50%	10%	10%	5%	70%
2030	100%	40%	50%	100%	25%	30%	30%	80%
2035		100%			50%	80%	80%	90%
2050		100%						

A = motorcycles and mopeds B = passenger cars C = vans D = urban buses
E = coaches F = HGVs < 16t G = HGVs < 16t H = rail

4 Results

The Vissim software enables vehicle movement simulation based on a discrete time step and a stochastic microscopic model, which includes Wiedemann car following psycho-physical driver behavior. In this way, it was possible to create a CO_2 concentration map for the studied area in VERSIT+ calculation model. The roundabout scheme, which is analysed, is characterised by a main direction of vehicular flow (North-South) and secondary direction (East-West), as it can be seen in Fig. 6.

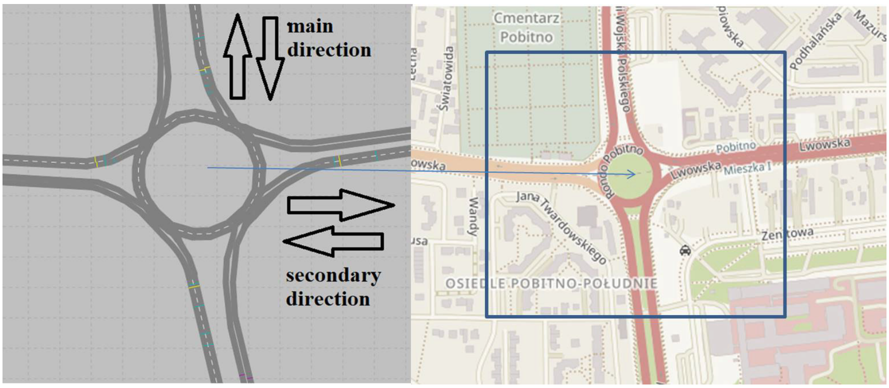

Fig. 6. Definition of the case study area and relative traffic directions.

The first analysed scenario expresses the existing situation, in which there are no electric vehicles. Figure 7 shows the distribution of CO_2 emissions, where the darker colour corresponds to a higher emission.

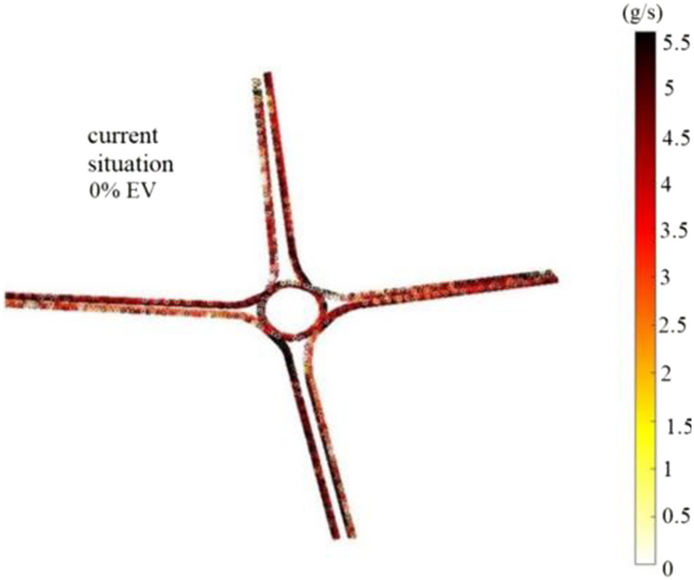

Fig. 7. Current scenario without e-fleet.

For the second scenario, the electric fleet was increased by 5%, by replacing a proportion of the combustion-powered light vehicles. The results are shown in Fig. 8.

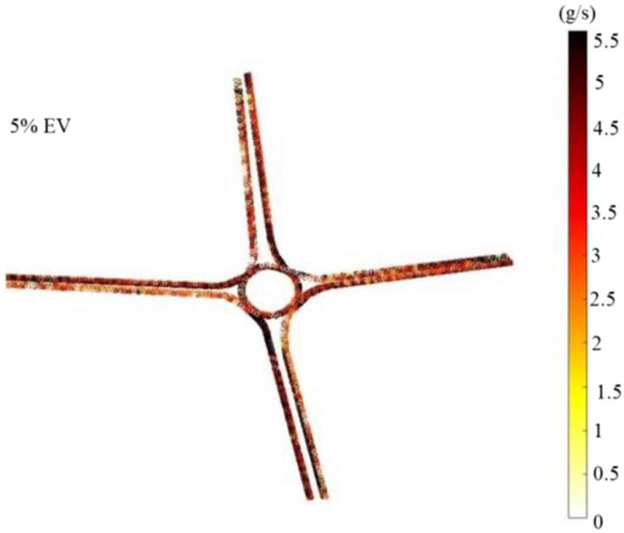

Fig. 8. Increase of 5% of EV on current vehicle fleet.

Then, a 10% increase (comparing with the existing situation), of electric vehicles was assumed. The results are presented in Fig. 9.

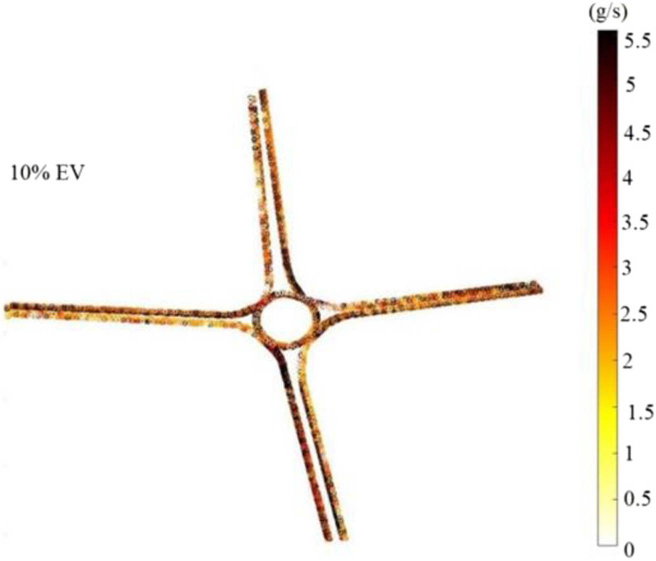

Fig. 9. Increase of 10% of EV on current vehicle fleet.

Figure 10 presents the results for the fourth scenario, with a 15% of the electric fleet.

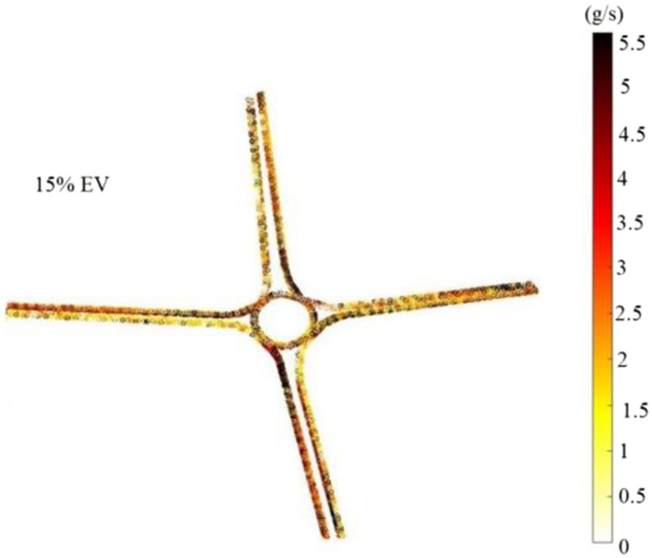

Fig. 10. Increase of 15% of EV on current vehicle fleet.

Finally, an insertion of 30% in accordance with European strategies was considered and the layout that is presented in Fig. 11 shows a substantial reduction in emissions.

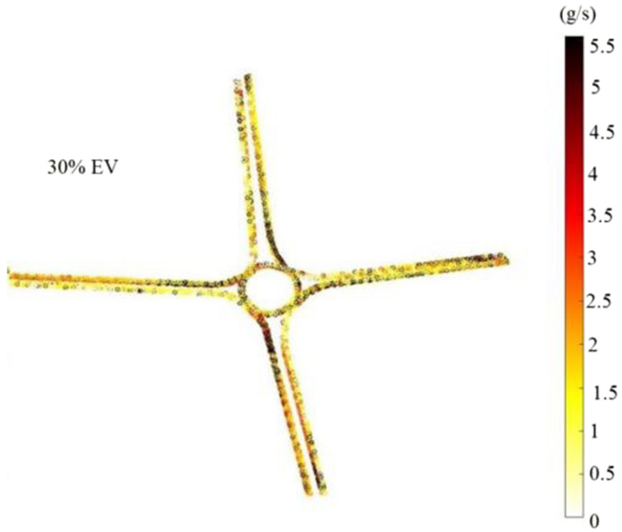

Fig. 11. Increase of 30% of EV on current vehicle fleet.

To summarize the results, Fig. 12 compares the CO_2 concentrations in the five scenarios. It shows that a 30% share of electric vehicles in the fleet could reduce CO_2 emissions from about 340 to about 220 (g/km).

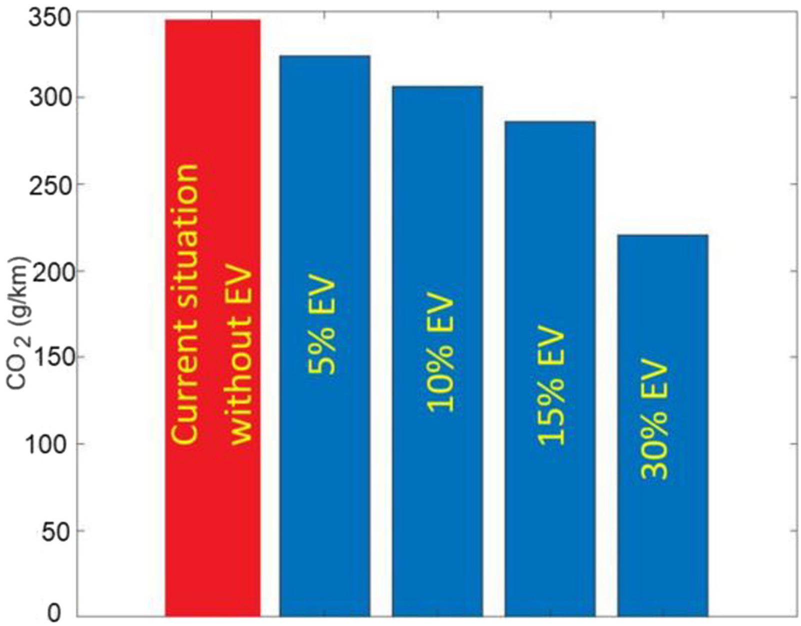

Fig. 12. Comparion of results in relation with e-fleet rate.

5 Conclusion and Discussion

Air pollution that is produced by the road transport sector, is one of the greatest threats for the environment. This is due to the predominance of road transport modes over other modes of transport, but also due to the fact that the emission of pollutants is being concentrated mainly on dense urban areas. This is also an outcome of the increased mobility of people and goods in modern societies.

Several strategies have been implemented worldwide to discourage the use of internal combustion engine vehicles and to encourage the use of greener means of transport, such as walking or cycling. Also, a great effort is being made to replace high-emission vehicles with low-emission ones and especially with electric vehicles, either private or public.

However, the increased mobility needs are directly linked with an increased negative impact on the environment. The demographic development, the expansion of urban agglomerations and the centralisation of services and activities in urban centres have led to extremely increased traffic volumes. In turn, this has led to frequent phenomena of congestion and therefore to a deterioration of the air quality. The monitoring of air pollution makes possible to obtain very precise information on the pollutants' concentrations and to make valuable comparisons.

However, this approach is generally applied for the detection of a limited number of pollutants (e.g. COx and NOx) comparing with the number of different pollutants that are being released into the atmosphere (e.g. aromatic compounds, heavy metals, etc.). Furthermore, this approach is not able to provide information for all areas, due to an unavailability of sensors, as well as for future scenarios. For a more holistic approach regarding the identification of the environmental conditions and degradation, it is particularly useful to combine the abovementioned sensors with simulation tools (models). Therefore, in the context of these general considerations, the present paper investigates the improvement of the air quality due to the introduction of electric vehicles and quantifies the CO_2 savings, using a specific micro-simulation software.

The simulation results prove that the introduction of electric vehicles in the fleets reduce significantly the CO_2 emissions. Even a 10% of electric vehicles in the total fleet can provide a substantial reduction of emissions, while a 30% penetration of electric vehicles can have an extremely positive impact. The specific conclusion shows that the efforts for the promotion of electromobility need to be enhanced, by providing adequate subsidies to the users. The purchasing cost of electric vehicles remain the greatest obstacles in adopting electromobility, but it is anticipated that this obstacle can be overcome with the subsidies' aid. Additionally, the implementation of complete charging networks is considered as a prerequisite for increasing electric vehicles' penetration. However, countries such as Norway, Sweden and the Netherlands have already showed the path, proving that the right measures can have a positive impact.

This research lays the foundations for future investigation considering not only light but also heavy electric vehicles for showing in a preventive way the benefits related to the reduction of internal combustion engine vehicles.

Acknowledgments. The authors acknowledge financial support from the MIUR (Ministry of Education, Universities and Research [Italy]) through a project entitled WEAKI TRANSIT: WEAK-demand areas Innovative TRANsport Shared services for Italian Towns (Project code:

20174ARRHT/CUP Code: J74I19000320008), financed with the PRIN 2017 (Research Projects of National Relevance) program. We authorize the MIUR to reproduce and distribute reprints for Governmental purposes, notwithstanding any copyright notations thereon. Any opinions, findings, and conclusions or recommendations expressed in this material are those of the authors and do not necessarily reflect the views of the MIUR.

Funding. This research work was partially funded by the MIUR (Ministry of Education, Universities and Research [Italy]) through a project entitled WEAKI TRANSIT.

Author Contributions. Conceptualization, T.C., S.B. and M.M.; methodology M.M and T.C.; software, M.M.; validation, T.C and M.M.; formal analysis, A.N.; resources M.M.; data curation, T.C.; writing—original draft preparation, T.C., S.B. and A.N.; writing—review and editing, S.B. and A.N.; visualization, T.C.; supervision, G.T.; project administration, T.C. All authors have read and agreed to the published version of the manuscript.

Conflicts of Interest. The authors declare no conflict of interest.

References

1. European Commission: White Paper: Roadmap to a Single European Transport Area – Towards a competitive and resource efficient transport system, Brussels (2011)
2. European Commission: The European Green Deal, Brussels (2019)
3. Pietrzak, K., Pietrzak, O.: Environmental effects of electromobility in a sustainable urban public transport. Sustainability **12**, 1052 (2020)
4. Campisi, T., Deluka-Tibljaš, A., Tesoriere, G., Canale, A., Rencelj, M., Šurdonja, S.: Cycling traffic at turbo roundabouts: some considerations related to cyclist mobility and safety. Transp. Res. Procedia **45**, 627–634 (2020)
5. Hydén, C., Várhelyi, A.: The effects on safety, time consumption and environment of large scale use of roundabouts in an urban area: a case study. Accid. Anal. Prev. **32**(1), 11–23 (2000)
6. Gavanas, N., Pitsiava-Latinopoulou, M., Basbas, S.: Pedestrian safety requirements at urban roundabouts: a case study in three roundabouts in Greece. ICASTOR J. Eng. **3**(3), 223–238 2010 (2010)
7. Lakouari, N., Oubram, O., Bassam, A., Pomares Hernandez, S.E.R., Ez-Zahraouy, M.H.: Modeling and simulation of CO2 emissions in roundabout intersection. J. Comput. Sci. **40**, 101072 (2020). https://doi.org/10.1016/j.jocs.2019.101072
8. Fernandes, P., et al.: Impacts of roundabouts in suburban areas on congestion-specific vehicle speed profiles, pollutant and noise emissions: an empirical analysis. Sustain. Cities Soc. **62**, 102386 (2020)
9. Martin-Gasulla, M., Elefteriadou, L.: Traffic management with autonomous and connected vehicles at single-lane roundabouts. Transp. Res. Part C Emerg. Technol. **125**, 102964 (2021)
10. Gonzalez, D., Pérez, J., Milanés, V.: Parametric-based path generation for automated vehicles at roundabouts. Expert Syst. Appl. **71**, 332–341 (2017)
11. Velten, E.K., Brauer, C., Thie, J.E.: Used vehicle trade and fleet composition in Europe (2019)
12. Wawer, M., et al.: Traffic-related pollutants in roadside soils of different countries in Europe and Asia. Water Air Soil Pollut. **226**(7), 1–14 (2015)
13. Łowicki, D.: Landscape pattern as an indicator of urban air pollution of particulate matter in Poland. Ecol. Ind. **97**, 17–24 (2019)

14. Chen, T.D., Wang, Y., Kockelman, K.M.: Where are the electric vehicles? a spatial model for vehicle-choice count data. J. Transp. Geogr. **43**, 181–188 (2015)
15. Tesoriere, G., Campisi, T.: The benefit of engage the "crowd" encouraging a bottom-up approach for shared mobility rating. In: Gervasi, O. et al. (eds) Computational Science and Its Applications – ICCSA 2020. ICCSA 2020. Lecture Notes in Computer Science, vol 12250. Springer, Cham (2020). https://doi.org/10.1007/978-3-030-58802-1_60
16. Kaya, Ö., Alemdar, K.D., Çodur, M.Y.: A novel two stage approach for electric taxis charging station site selection. Sustain. Cities Soc. **62**, 102396 (2020)
17. Askari, S., Peiravian, F., Tilahun, N., Yousefi Baseri, M.: Determinants of users' perceived taxi service quality in the context of a developing country. Transp. Lett. **13**(2), 125–137 (2021)
18. Papanikolaou, A., Basbas, S.: Analytical models for comparing demand responsive transport with bus services in low demand interurban areas. Transp. Lett. **13**, 1–8 (2020)
19. Abdullah, M., Ali, N., Shah, S.A.H., Javid, M.A., Campisi, T.: Service quality assessment of app-based demand-responsive public transit services in Lahore Pakistan. Appl. Sci. **11**(4), 1911 (2021)
20. Campisi, T., Canale, A.,Ticali, D., Tesoriere, G.: Innovative solutions for sustainable mobility in areas of weak demand. Some factors influencing the implementation of the DRT system in Enna (Italy). In AIP Conference Proceedings, vol. 2343, pp. 090005. AIP Publishing LLC March 2021. https://doi.org/10.1063/5.0047765
21. Bienias, K., Kowalska-Pyzalska, A., Ramsey, D.: What do people think about electric vehicles? an initial study of the opinions of car purchasers in Poland. Energy Rep. **6**, 267–273 (2020)
22. https://www.statista.com/statistics/1081299/poland-number-of-electric-passenger-vehicles/. Accessed 1 Dec 2020
23. Campisi, T., Tesoriere, G., Sanfilippo, L., Brignone, A., Canale, A.: Exploring the TTMS's impact to the accessibility of a long distance stretch using micro-simulation approach. In: Gervasi O. et al. (eds) Computational Science and Its Applications – ICCSA 2020. ICCSA 2020. Lecture Notes in Computer Science, vol. 12250. Springer, Cham July 2020. https://doi.org/10.1007/978-3-030-58802-1_55
24. Tesoriere, G., Campisi, T., Canale, A., Zgrablić, T.: The surrogate safety appraisal of the unconventional elliptical and turbo roundabouts. J. Adv. Transp. (2018)
25. Rotaris, L., Giansoldati, M., Scorrano, M.: The slow uptake of electric cars in Italy and Slovenia. Evidence from a stated-preference survey and the role of knowledge and environmental awareness. Transp. Res. Part A Policy Pract. **144**, 1–18 (2021)
26. Campisi, T., Mrak, I., Canale, A., Tesoriere, G.: The surrogate safety measures evaluation of a staggered crossing on the delta area of Rijeka. In: AIP Conference Proceedings, vol. 2186, no. 1, p. 160006. AIP Publishing LLC, December 2019
27. Basbas, S., Campisi, T., Canale, A., Nikiforiadis, A., Gruden, C.: Pedestrian level of service assessment in an area close to an under-construction metro line in Thessaloniki, Greece. Transp. Res. Procedia **45**, 95–102 (2020)
28. Tollazzi, T., Tesoriere, G., Guerrieri, M., Campisi, T.: Environmental, functional and economic criteria for comparing "target roundabouts" with one-or two-level roundabout intersections. Transp. Res. Part D Transp. Environ. **34**, 330–344 (2015)
29. Mądziel, M., Campisi, T., Jaworski, A., Tesoriere, G.: The development of strategies to reduce exhaust emissions from passenger cars in Rzeszow city—Poland a preliminary assessment of the results produced by the increase of e-fleet. Energies **14**(4), 1046 (2021)
30. Jaworski, A., Mądziel, M., Lejda, K.: Creating an emission model based on portable emission measurement system for the purpose of a roundabout. Environ. Sci. Pollut. Res. **26**(21), 21641–21654 (2019). https://doi.org/10.1007/s11356-019-05264-1

31. Madziel, M., Jaworski, A., Savostin-Kosiak, D., Lejda, K.: The impact of exhaust emission from combustion engines on the environment: modelling of vehicle movement at roundabouts. Int. J. Automot. Mech. Eng. **17**(4), 8360 (2020). https://doi.org/10.15282/ijame.17.4.2020.12.0632
32. Gębarowski, M., Wiażewicz, J.: Transport Congestion (in Polish Cities)–Rzeszow in Comparison to the Biggest Cities in Poland
33. Smieszek, M., Dobrzanska, M., Dobrzanski, P.: Rzeszow as a city taking steps towards developing sustainable public transport. Sustainability **11**(2), 402 (2019)
34. Dobrzański, P.D., Smieszek, M.S., Dobrzańska, M.D.: Rzeszow as a City Taking Steps towards Developing Sustainable Public Transport (2019)