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The Role of Cold Ironing in Maritime Transport Emissions

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Abstract. Maritime Transport is one of the sources of atmospheric pollution, contributing with gaseous emissions mainly caused by marine engines and fossil fuel combustion, and characterized by the production of substances such as CO_2, CO, NO_x, SO_x and PM_x, harmful to the environment and human health. Cold Ironing, also known as Alternative Maritime Power (AMP) or Shoreside Supply, is one of the most relatively recent technologies designed to reduce emissions in the maritime industry: it consists in a three-parts system to connect shore-side located power sources, especially with renewable energies and smart grids, to on-board systems able to receive and store electricity, through intermediate connection devices that allow electricity to flow from the port into ships. This technology has been proved to bring financial and environmental benefits, considering also the rise in fuel costs; however, it is still facing some challenges in getting widespread worldwide, mainly due to retrofitting and upgrade costs. It will also require more specific policies and regulations involving stakeholders of different technical and geographical nature. Scientific research is however promising under all these aspects, as it is demonstrating significant reductions in terms of emissions and externalities.

INTRODUCTION

Cold Ironing (CI) is a relatively recent technology in maritime transport, and consists in connecting ships to quays in order to supply electricity from the inland network in port. This way, all the onboard facilities that require electricity can be powered up through the inland network, and onboard engines can be switched off leading to a consequent reduction in emissions **[1]**. This can reach significant levels of relevance if considering large vessels such as tankers and cruise ships, the latter being compared to seaborne small towns. Since the abatement of emissions is achieved by switching onboard engines off, this is heavily influenced by several factors such as type of engine and RPMs, type of fuel in combustion, and even by the type of inland power sources, because if the port electricity network is powered by green energies (photovoltaic, wind etc.) rather than fossil, and optimized via a smart-grid system, this will have a positive impact on a large scale too in terms of emissions. It has been demonstrated that Cold Ironing can reduce local emissions up to 70% for CO_2, to 60% for SO_x and up to 60% for NO_x in a container terminal port **[2]**. The application of Cold Ironing requires installing specific technical devices in ports, and to make sure that ship and inland electrical systems have compatible characteristics; inland electricity must also be sufficient and of good quality, so to avoid the risk of network overloads: this leads to associated costs that might be challenging too small ports or in developing economies, which might also face a problem of electricity availability.

BACKGROUND AND STATE OF ART

The impact on atmosphere from maritime transport is mainly caused by polluting emissions from onboard engines, due to the production of chemical substances such as GHG and CAC like CO2, NOX or PMx, which are harmful to the environment or to human health: Greenhouse Gases and CO2 in particular contribute to the

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phenomenon of Greenhouse Effect, and CAC can cause or aggravate respiratory problems and diseases. International organizations like IMO dedicate much effort in order to tackle this problem, developing international treaties like the International Convention for the Prevention of Pollution from Ships (MARPOL 73/78) and promoting policies that often get translated into official regulations, setting thresholds and restrictions for maritime emissions worldwide. European Directives for example set the maximum sulfur content in marine fuels for berthed ships to 0.1% **[3]**. Since Cold Ironing is a relatively recent technology, the amount of available dedicated literature and enforced regulations is relatively scarce, focusing more on the financial impacts rather than environmental benefits; this is particularly true for the topic of interaction between Cold Ironing and Smart-Grids powered by renewables. Since the financial aspect is very important for shipping companies and port authorities, the application of Cold Ironing could be incentivized through the implementation of financial benefits to those stakeholders that move towards this technology, by tax reductions for reduced emission for example or with monetary environmental "tokens" to be spent for port or ship upgrades; this could be an alternative modern approach instead of the more traditional system of fines and penalties to uncompliant stakeholders (or they could be used simultaneously). In terms of costs, the annual net costs or benefits for Cold Ironing technologies sustained by a port authority can be calculated with mathematical functions that consider the number and type of vessels relying on Cold Ironing, the price of electricity per kWh bought from the network (if not self-produced) and sold to the ship (only the amount related to Cold Ironing), and any financial incentives to the port and to ships **[4]**. Despite its recent development, Cold Ironing is however becoming more widespread and dedicated research will surely be appreciated in this sense. Currently, Cold Ironing is mostly spread in North America and Europe, but also in Asia and Oceania, as shown in **FIGURE 1 [5]**.

FIGURE 1. Cold Ironing Worldwide (by March 2017) **[5]**.

GENERAL TECHNICAL ASPECTS

The main benefit in terms of emission reduction comes from switching off onboard engines, thus reducing or eliminating combustion plumes. Emissions for moored vessels can be estimated with equations that consider variables such as the Specific Oil Consumption, the fraction of engine nominal power in use, nominal power of auxiliary engines and the duration of hoteling at berth **[6]**. A typical Cold Ironing system is made of three sections: the onshore electricity supply system, the connection system between ship and quay, and an onboard system to receive electricity. On board and in-land electricity must present consistent characteristics: this aspect has particular importance for international ports, as electricity standards and devices are different across the globe. Off-shore electricity can be obtained from the main inland electricity network (national grids), but also from local autonomous grids powered by renewable sources such as photovoltaic and wind farms, or LNG power plants, providing additional environmental benefits: it has been demonstrated that integrated systems of Cold Ironing and Cogeneration Power Plants can lead to the prevention of 110 tonnes of NO_x, over 2 tonnes of PM_{10} and over than 4 tonnes of SO_x per year; best setups can even abate emissions by 98.58% for NO_x, 79,06% for PM_{10}, and 100% for SO_x **[7]**. **[8]**. **Figure 2** schematizes the Shore-Side Power (SSP) system to connect ships with port quays **[9].** Smart grids and onboard managed and optimized thanks to Artificial Intelligence and computer algorithms **[10]**.

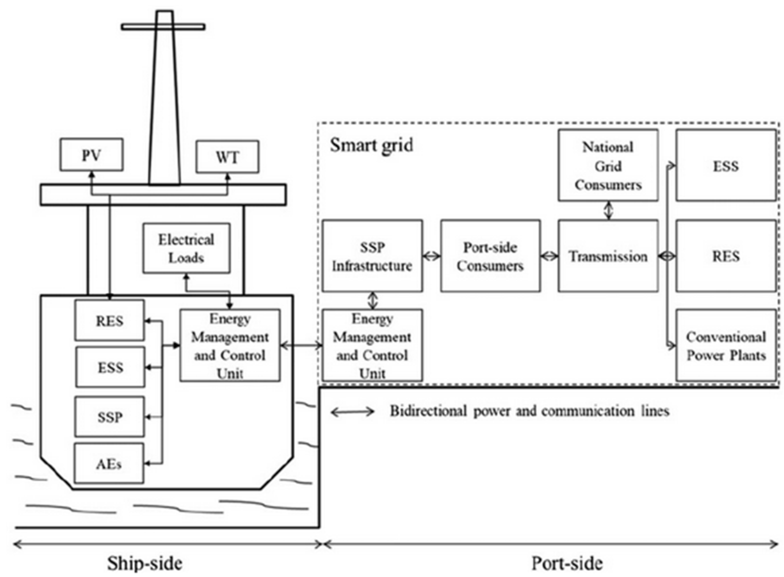

FIGURE 2. In-land network connected to berthed ships via Cold Ironing **[9].**

CASE STUDIES

Two Case Studies will be now described as an example of how Cold Ironing can applied to existing ports bringing environmental benefits. In the first study **[11]**, researchers have performed data analysis on ship emissions at berth during year 2013, applying two different methods to estimate them: a statistical approach and another recommended ship movement methodology when data is available. Total emissions were calculated as a sum of single contribution from hoteling, maneuvering and cruising for each individual ship, considering technical parameters like the time spent at the port and average fuel consumption of the auxiliary machinery. The findings are shown in **Table 1** below. Finally, given the unit costs per ton of emission, total costs were calculated and its comparison with total fuel costs showed the first to be higher than the latter. Another calculation returned the amount of necessary electricity from renewable energies in order to turn off auxiliary machinery and rely on the shore-side grid, demonstrating that this would allow to save \$23M a year in externalities. The costs to build the necessary infrastructure to upgrade the port haven't been calculated, however given the expensiveness of this technology, authors suggest to rely on credit systems like subsidies.

TABLE 1. Estimated emissions by ship type for the Iskenderun Port in 2013 **[11].**

Ship Type	Total Emissions (t)					
	NOx	PM	CO	VOC	SOx	CO2
Bulk Carrier	331	8	13	10	292	17,258
Container	24	1	1	1	21	1,249
General Cargo	485	12	19	15	428	25,287
Oil & Chemical Tanker	22	1	1	1	19	1,126
Multipurpose Dry Cargo	321	8	13	10	283	16,725
Total	**1,183**	**30**	**47**	**37**	**1,043**	**61,645**

The other study **[12]** examined the implications of Cold Ironing for ships during their hoteling maneuvers, underlining the substantial economic convenience of Smart Grids and Cold Iron if compared to high and rising fuel prices. However, since emission regulations and restrictions affect the entire journey of a ship, stakeholders can often prefer investing in full-round technology like scrubbers rather than shore-side systems, despite the significant environmental benefits of a ship berthed with Cold Ironing. Currently, only a low number of existing ports is already employing this technology and similarly, there aren't enough retrofitted ships to make a significant difference, with a low penetration rate. In future, new ports and ships might be equipped with shore-side systems so that their spread may become mainstream and more economically convenient and accepted. This can be achieved also thanks to coordinated policies and management transport systems **[13, 14]** that involve all the main stakeholders within transport industry **[15, 16, 17, 18]**. **Figure 3** shows the different penetration rates (r_k in %) for Medium Fuel Price (left) and 25% penetration for Low, Medium and High Fuel Prices (right).

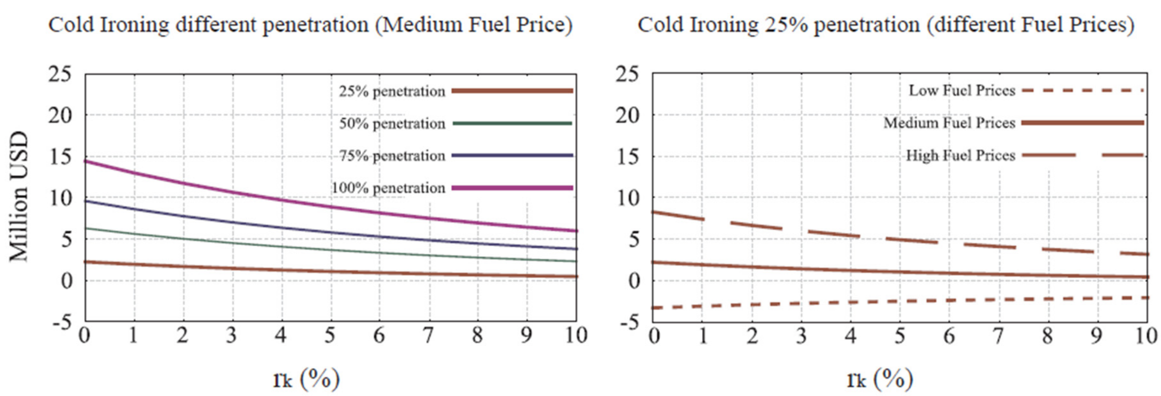

FIGURE 3. In-land network connected to berthed ships via Cold Ironing **[12].**

DISCUSSION

Cold Ironing is an interesting and recent technology that is already proving its efficacy, both in terms of sustainability and financial convenience that is related to all transport systems **[19, 20, 21]**. It is an example of multidisciplinary approach, as its applications involve many fields of science and engineering, such as civil engineering and construction, electronics, Artificial Intelligence, environmental chemistry and so on **[22, 23]**. The availability of recent literature is not very generous, with many studies focusing on the financial aspects rather than environment and sustainability (although them being strictly related). A further progress in Cold Ironing might involve Artificial Intelligence and software algorithms, applied for example in smart grids to automatically understand the electricity demand and therefore adjust the supply rate. Another application could be done to Autonomous Vessels (considering the spread of autonomous vehicles) **[24, 25, 26]**, which are unmanned ships operated by computers in autonomy, ideally leading to higher efficiency with better routing and optimized in-port maneuvers, meaning better fuel consumption, reduced emissions and reduced costs as well. Smart grids can be either thought on-shore or off-shore, with electrical grids installed on vessels relying perhaps on renewable energy, mostly photovoltaic with solar panels, but wind is also coming back under the spotlight recently, after centuries of being abandoned as a propulsion source. To date, renewable energies can perhaps find easier application on shore, creating sustainable autonomous power plants and electricity grids to power up vessels through Cold Ironing, but also any other vehicle or machinery inside the port **[27, 28, 29, 30]**. It must be noted that shore-side and on-board systems must present the same characteristics for electricity, since standards may vary worldwide **[31, 32]**. Cold Ironing technology is currently relatively expensive; thus, some effort will be required also in terms of regulations and funding, speaking i.e., about well calibrated policies with reward and penalty systems, like for example assigning credits to virtuous stakeholders or setting high charges for those who don't comply; Information Technology today is able to help with the calibration of this multi-parameter models **[33, 34, 35]**, but it must be remembered that not all ports and stakeholders are currently financially able to upgrade their fleet and infrastructure to chase the environmental transition for a greener future **[36, 37, 38]**.

CONCLUSIONS

Cold Ironing, also known as Alternative Maritime Power (AMP) and shore-side power supply, is a relatively recent technology that consists in electrically connecting receptive ships to properly equipped ports, via dedicated technology that allows transferring electricity from the shore side to vessels. Although the financial and environmental benefits obtained through Cold Ironing systems have already been proven, these systems still struggle to become mainstream, and remain confined to a relatively low number of ports and vessels in the world. One of the main reasons is that, although CI allows to save on the costs of fuel burned by ships during mooring, shipping companies still prefer to invest in all-round solutions that affect the entire voyage of the ship, like scrubbers. Port Authorities, on the other side, couldn't be financially ready to upgrade their infrastructures, as these systems are still somewhat expensive; perhaps with them becoming of common use, their costs would lower down significantly. Recent research studies show however how significant are the environmental and financial benefits coming from their application, with heavily reduced emission levels of CO_2, NO_x, SO_x and PM_x and cost savings, especially if integrated with dedicated renewable energy plants. The deployment of sustainable strategies and cold ironing in ports together with the implementation of urban and transport planning aimed at decarbonisation can mitigate environmental impacts, e.g. by favouring the use of alternative forms of mobility or innovative non-combustion engines **[39,40,41,42,43]** .Stakeholders could be attracted to Cold Ironing by subsidies and credit systems, but also pushed towards them with stricter regulations and higher charges. Future research might be directed in order to make these systems more efficient through Artificial Intelligence, more affordable and thus more widespread worldwide.

REFERENCES

1. J. Prousalidis; D. Lyridis; S. Dallas; Z. Soghomonian; V. Georgiou; D. Spathis; T. Kourmpelis; P. Mitrou. Ship to shore electric interconnection: From adolescence to maturity - *EEE Electric Ship Technologies Symposium* – 2017
2. T.P.V. Zis, Green Ports - Sustainable Shipping: A Cross-Disciplinary View – 2019
3. ESPO, Environmental Code of Practice – 2004
4. T. Zis, R. North, P. Angeloudis, Panagiotis, W. Ochieng, B. Michael. (2014). Evaluation of cold ironing and speed reduction policies to reduce ship emissions near and at ports. Maritime Economics & Logistics. 16. 371-398. 10.1057/mel.2014.6.
5. Cold Ironing – Future Energy for Future Ports. Bilbao, March 29th 2017
6. Zis, Thalis P.V., 2019. "Prospects of cold ironing as an emissions reduction option," Transportation Research Part A: Policy and Practice, Elsevier, vol. 119(C), pages 82-95
7. F. Esposito, E. Mancinelli, M. Morichetti, G. Passerini, U. Rizza. A cogeneration power plant to integrate cold ironing and district heating and cooling - International Journal of Energy Production and Management – 2018
8. Microgrids Technologies in Future Seaports – Binti Ahmad, N.B. - International Conference on Environment and Electrical Engineering and 2018 IEEE Industrial and Commercial Power Systems Europe (EEEIC / I&CPS Europe) - Palermo, Italy – 2018

9. K. Yiğit, B.Acarkan. (2018). A new electrical energy management approach for ships using mixed energy sources to ensure sustainable port cities. Sustainable Cities and Society. 40. 10.1016/j.scs.2018.04.004.
10. Z. Amjad, M. Shah, C. Maple, H.A. Khattak, Z. Ameer, M. Asghar, S. Mussadiq. (2020). Towards Energy Efficient Smart Grids Using Bio-Inspired Scheduling Techniques. IEEE Access. PP. 1-1. 10.1109/ACCESS.2020.3020027.
11. A. Kılıç, M. YOLCU, F. Kılıç, L. Bilgili. (2020). Assessment of Ship Emissions through Cold Ironing Method for Iskenderun Port of Turkey. Environmental Research and Technology. 10.35208/ert.794595.
12. A. Martinez Lopez, A. Romero-Filgueira, M. Chica-Gonzalez,. - Specific Environmental Charges to boost Cold Ironing use in the European Short Sea Shipping - *Transportation Research Part D Transport and Environment* – 2021
13. S. Cafiso, G Pappalardo. "Safety effectiveness and performance of lane support systems for driving assistance and automation – Experimental test and logistic regression for rare events", Accident Analysis & Prevention, Volume 148, December 2020, doi:10.1016/j.aap.2020.105791
14. G. Pappalardo, S. Cafiso, A. Di Graziano, A. Severino. "Decision tree method to analyze the performance of lane support systems", Sustainability, Volume 13, Issue 2, Pages 1 - 12 Article number 846, doi:10.3390/su13020846
15. S. Cafiso, A. Di Graziano, G. Pappalardo. "Road safety issues for bus transport management", Accident Analysis & Prevention, Volume 60, November 2013, Pages 324–333 ISSN 0001-4575 doi:10.1016/j.aap.2013.06.010
16. S. Cafiso, A. Di Graziano, G. Pappalardo. "Using the Delphi method to evaluate opinions of public transport managers on bus safety", Safety Science, Volume 57, 2013, Pages 254-263, DOI: 10.1016/j.ssci.2013.03.001.
17. S. Cafiso, A. Di Graziano, G. Pappalardo "In-vehicle Stereo Vision system for identification of traffic conflicts between Bus and Pedestrian", Journal of Traffic and Transportation Engineering, Volume 4, pp. 3-13, 2017 DOI: 10.1016/j.jtte.2016.05.007, ISSN: 2095-7564
18. G. Pappalardo, S. Cafiso, A. Severino. "Development of simulated scenarios for quadricycle safety", Civil Engineering and Architecture, 2021, 9(3), pp. 584–594, doi:10.13189/cea.2021.090302
19. X. Wang, D. Qina, S. Cafiso, K. Liang, X. Zhua. "Operational design domain of autonomous vehicles at skewed intersection". Accident Analysis & Prevention, Volume 159, September 2021, 106241
20. E. Murgano, R. Caponetto, G. Pappalardo, S. Cafiso, A. Severino "A novel acceleration signal processing procedure for cycling safety assessment", Sensors, Volume 21, Issue 122 June 2021 Article number 4183, doi: 10.3390/s21124183
21. S. Cafiso, C. D'Agostino, M. Kiec, G. Pappalardo, "Surrogate measure of safety from road inspection data - experimental test on Polish roads / Wykorzystanie danych z kontroli bezpieczeństwa ruchu drogowego jako pośredniej miary bezpieczeństwa - badania na polskich drogach", Roads and Bridges - Drogi i Mosty Vol.16, 2, 2017, 115-130, jun. 2017. ISSN 2449-769X DOI: 10.7409/rabdim.017.008
22. S. Cafiso, A. Di Graziano, G. Pappalardo "Safety inspection and management tool for low-volume road network", Transportation Research Record: Journal of the Transportation Research Board, No. 2472, 2015, ISBN 978-0-309-29571-0
23. S. Cafiso, A. Montella, C. D'Agostino, F. Mauriello, F. Galante. "Crash modification functions for pavement surface condition and geometric design indicators". Accident Analysis and Prevention Volume 149, 2021 Article number 105887. DOI 10.1016/j.aap.2020.105887
24. S. Cafiso, A. Di Graziano, D.G. Goulias, C. D'Agostino. "Distress and profile data analysis for condition assessment in pavement management systems". International Journal of Pavement Research and Technology, Volume 12, Issue 5, Pages 527 – 5361, 2019. DOI 10.1007/s42947-019-0063-7
25. S. Cafiso, A. Di Graziano, G. Pappalardo, O. Giudice. "Using GPS data to detect critical events in motorcycle rider behavior", International Journal of Mobile Network Design and Innovation - Vol. 5, No. 4, 2014, PP. 195 – 204, ISSN 1744-2869
26. S. Cafiso, G. La Cava, G. Pappalardo. "A logistic model for Powered Two-Wheelers crash in Italy". Procedia - Social and Behavioral Sciences, SIIV-5th International Congress - Sustainability of Road Infrastructures 2012, Volume 53, 2012, Pages 881-890, ISSN 1877-0428 DOI 10.1016/j.sbspro.2012.09.937
27. N. Stamatiadis, G. Pappalardo, S. Cafiso, "A Comparison of Bicyclist Attitudes in Two Urban Areas in USA and Italy" In: Nathanail E., Karakikes I. (eds) Data Analytics: Paving the Way to Sustainable Urban

Mobility. CSUM 2018. Advances in Intelligent Systems and Computing, vol 879, pp 272-279. Springer, Cham DOI: 10.1007/978-3-030-02305-8_33
28. S. Cafiso, C. D'Agostino, M. Kiec, R. Bak. "Safety assessment of passing relief lanes using microsimulation-based conflicts analysis". Accident Analysis and Prevention, Volume 116, Pages 94 – 102, 2018. DOI 10.1016/j.aap.2017.07.001
29. S. Cafiso, A. Di Graziano, G. Pappalardo. "How to compare different national databases of HGV accidents to identify issues for safety improvements" The Baltic Journal of Road and Bridge Engineering - Vilnius: Technika, 2013, Vol 8, No 2, p. 124-132 DOI:10.3846/bjrbe.2013.16
30. S. Curto, A. Severino, S. Trubia, F. Arena, L. Puleo. The effects of autonomous vehicles on safety. AIP Conference Proceedings, 2021, 2343, 110013
31. A. Severino, L. Martseniuk, S. Curto, L. Neduzha. Routes Planning Models for Railway Transport Systems in Relation to Passengers' Demand. Sustainability 2021, 13, 8686. https://doi.org/10.3390/su13168686
32. A. Severino, S. Curto, S. Barberi, F. Arena, G. Pau. Autonomous Vehicles: An Analysis Both on Their Distinctiveness and the Potential Impact on Urban Transport Systems. Applied Sciences. 2021; 11(8):3604. https://doi.org/10.3390/app11083604
33. S. Trubia, A . Severino, S . Curto, F. Arena, G. Pau. Smart Roads: An Overview of What Future Mobility Will Look Like. Infrastructures. 2020; 5(12):107. https://doi.org/10.3390/infrastructures5120107
34. S. Trubia, A. Severino, S. Curto, F. Arena, G. Pau. On BRT Spread around the World: Analysis of Some Particular Cities. Infrastructures. 2020; 5(10):88. https://doi.org/10.3390/infrastructures5100088
35. S. Barberi, M. Sambito, L. Neduzha, A. Severino. Pollutant Emissions in Ports: A Comprehensive Review. Infrastructures 2021, 6, 114. https://doi.org/10.3390/infrastructures6080114
36. G. Pau, A. Severino, A. Canale. Special Issue "New Perspectives in Intelligent Transportation Systems and Mobile Communications towards a Smart Cities Context". Future Internet. 2019; 11(11):228. https://doi.org/10.3390/fi11110228
37. F. Arena, G. Pau, A. Severino, S. Trubia, S. Curto. Future Connected Cars Through the Evolution of Telematics and Infotainment, (2021) International Journal on Engineering Applications (IREA), 9 (2), pp. 49-61. doi:https://doi.org/10.15866/irea.v9i2.20193
38. M. Giliberto, F. Arena and G. Pau. A fuzzy-based Solution for Optimized Management of Energy Consumption in e-bikes, J. Wirel. Mob. Networks Ubiquitous Comput. Dependable Appl. 2019, vol.10, pp.45-64
39. Ö. Kaya, K.D. Alemdar, T. Campisi, A. Tortum, & M.K. Çodur. (2021). The Development of Decarbonisation Strategies: A Three-Step Methodology for the Suitable Analysis of Current EVCS Locations Applied to Istanbul, Turkey. Energies, 14(10), 2756.
40. M. Ashraf Javid, N. Ali,M. Abdullah, T. Campisi & S.A.H. Shah. Travelers' Adoption Behavior towards Electric Vehicles in Lahore, Pakistan: An Extension of Norm Activation Model (NAM) Theory. Journal of Advanced Transportation, 2021.
41. M.Mądziel, T. Campisi, A. Jaworski, & G.Tesoriere (2021). 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.
42. M. Mądziel, T. Campisi,A. Jaworski,H. Kuszewski, P. & Woś (2021). Assessing Vehicle Emissions from a Multi-Lane to Turbo Roundabout Conversion Using a Microsimulation Tool. Energies, 14(15), 4399.
43. F. Moraci, M.F. Errigo,C. Fazia,T. Campisi & F. Castelli (2020). Cities under pressure: Strategies and tools to face climate change and pandemic. Sustainability, 12(18), 7743.