Insight Paper: Road safety aspects of quiet Electric Vehicles in Africa and South Asia

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Abstract

Electric Vehicles (EVs) are projected by many to become mainstream in global road transport systems in the next two decades. While, from an air pollution, noise pollution, and climate change mitigation perspective, the mass substitution of Internal Combustion Engine Vehicles (ICEVs) with EVs can have clear benefits for urban environments, the fact that EVs are substantially noiseless at low speeds can pose some serious road safety issues. In fact, there are a number of potential scenarios that would see quiet EVs increase the risk of collision with pedestrians, cyclists, people with sight disabilities and other city users. This Insight Paper revolves around the key question of how to find the balance between tackling climate change, air pollution and noise pollution on the one hand, and improving road safety on the other hand. HVT's preliminary research shows that this is an under-researched topic, with no studies found in this area relating to low- and middle-income countries (LMICs). Therefore, examples from high-income countries are used in this paper as the basis to discuss the possible impact on road safety of EV penetration in LMICs in Africa and South Asia, as well as possible solutions and research gaps.

Keywords	Electric Vehicles, EVs, road safety, Acoustic Vehicle Alerting System, AVAS, noise pollution, air pollution, air quality, climate change
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EXECUTIVE SUMMARY

As sector with the fastest growing greenhouse gas (GHG) emissions, transport is at the forefront of the global low carbon transition. One of the most widely known actions to decarbonise global transport is shifting to electric mobility, coupling it with national grids run by renewable energy. Shifting to electric vehicles (EVs) can not only be beneficial in addressing climate change, but it also brings about a number of co-benefits in other transport-related issues, such as reduced air and noise pollution.

Indeed, **should the general urban population use EVs instead of ICEVs to go from A to B, our cities would sound very different, probably much quieter than today. However,** although noise pollution is a serious problem affecting global urban environments and disproportionally those in Low- and Middle-Income Countries (LMICs), **the fact that EVs are substantially noiseless at low speeds can pose some serious road safety issues.** In fact, there are a number of potential scenarios that would see quiet EVs increase the risk of collision with pedestrians, cyclists, people with sight disabilities and other city users.

This Insight Paper seeks to discuss the links between two key issues of today's global transport: electric vehicles and road safety. In particular, the document revolves around the key question of **how to find the balance between tackling climate change, air pollution and noise pollution on the one hand, and improving road safety on the other hand.** HVT's preliminary research shows that this is an under-researched topic, with no studies found in this area relating to Low-Income Countries (LICs). Therefore, examples from High-Income Countries (HICs) are used in this paper as the basis to discuss the possible impact on road safety of EV penetration in LMICs in Africa and South Asia, as well as possible solutions and research gaps.

BRIEF REVIEW OF THE IMPACT OF ROAD SAFETY, AIR POLLUTION AND NOISE POLLUTION ON HUMAN HEALTH

Road safety

According to the World Health Organisation (WHO), road traffic is the 8th leading cause of death (and 1st among non-health causes) for people of all ages and causes an estimated 1.4 million deaths each year.[6] Unsurprisingly, due to poor health and safety, road conditions, and other systemic problems, the large majority of road traffic related deaths occur in LMICs. To put it into perspective, the risk of death due to road traffic injuries is more than three times higher in LICs (27.5 deaths per 100,000 population) than in HICs (8.3 deaths per 100,000 population).[6]

Outdoor air pollution

Outdoor or ambient air pollution has been a substantial health hazard for modern societies since the beginning of the industrial revolution. It is estimated that 9 out of 10 of annual fatalities linked to outdoor air pollution occur in LMICs.[10]

There are many anthropogenic activities which cause ambient air pollution, such as fuel combustion from motor vehicles, heat and electricity generation, industrial processes, waste management, some agricultural practices, and some residential activities, including heating and cooking. In addition of being a serious health hazard, some outdoor air pollutants are also potent GHGs, causing climate change.

Although, road transport is not the only source of outdoor air pollution, it is certainly one of the most important. For example, the UK Department for Environment, Food and Rural Affairs (DEFRA) identifies road traffic emissions as the current "major threat to clean air", explaining that not only ICEVs account for a large proportion of different air pollutants, but also, they are able to spread them for long distances, contrarily to what happens with more stationary sources, such as power plants.[13] Indeed, there is scientific evidence confirming the ability of road traffic regulations[14] and the switch from ICEVs to EVs (coupled with a cleaner electricity mix)[15] of strongly reducing outdoor air pollution.

Noise pollution

Environmental noise pollution, i.e. unwanted disturbance provoked by noise from outdoor surroundings, is the other key form of environmental pollution related to road transport. **Motorised transport in urban**

settings is the main source of noise pollution and the problem is in expansion, driven by socio-economical dynamics, such as population growth, urbanisation and technological development.[16]

Noise pollution is a serious health hazard. The WHO estimates that every year 1 million "health years" of life is lost in Western Europe due to traffic noise.[17] Unsurprisingly, there is scientific evidence that the problem of noise pollution in LMICs is very serious. Research also shows a positive relationship between exposure to noise pollution and social inequalities indicators, although more research on this topic appears necessary.

ELECTRIC VEHICLES AND ROAD SAFETY IN HIGH INCOME COUNTRIES

The problem of quiet electric and hybrid electric vehicles for road safety

Generally, the noise of passing vehicles is composed of the noise of the engine or powertrain, and the noise of the tyres on the road. However, there is an important difference on this aspect between ICEVs and EVs (including hybrid electric vehicles (HEVs)): **at low speed, while for ICEVs the dominant source of noise is the powertrain, for EVs the powertrain noise is extremely low.**

Although this characteristic makes EVs very effective in mitigating noise pollution, **the absence of a recognisable audible presence can create a road safety hazard in low speed driving conditions**, which are most likely to occur in urban environments, the areas where the risk of collision with vulnerable road users is higher. Therefore, as the Road Safety Observatory points out, this highlights an important trade-off for policy-makers between "optimal noise levels for health and social well-being and optimal noise for the safety of pedestrians, cyclists and other road users who rely on vehicle noise as a warning sound."[25]

In the literature, there is contrasting evidence that EVs actually cause more collisions with vulnerable road users than ICEVs. Some literature has pointed out a higher collision rate of HEVs with pedestrians and cyclists while travelling at low speed[26], while other show no concrete evidence of a higher road safety risk posed by EVs.[27] However, some important limitations were identified in these studies and, what seems to emerge is that **further research is needed to determine the risk of quiet EVs to vulnerable road users.**

Although currently there seems to be no hard evidence to confirm the argument that quiet EVs cause more collisions with vulnerable road users than ICEVs, it is reasonable to expect that, with the substantial projected increase in EVs in circulation, more evidence (proving or disproving the argument) will come to light. Interestingly, from a study involving a survey of EV drivers in the city of Malaga in Spain, although a majority of interviewees confirmed that road safety events occurred while travelling below 30 Km/h, many of the EV drivers reported that they are conscious that other road users may not hear them at low speeds and therefore they pay particular attention in those key risk situations.

Regulatory solutions

The road transport regulators in HICs have been addressing the problem of quiet EVs with the addition of synthetic noise or EV Acoustic Vehicle Alerting Systems (AVASs). This is the case in the European Union, the UK, and the United States, where there are regulations that make the installation of AVASs mandatory on new EVs and HEVs, while in Asia, Japan and China have both introduced standards for AVASs.

One important limitation of all these regulatory instruments is that they do not cover requirements for two- or three-wheelers. This exclusion can be substantial in curtailing the effectiveness of similar regulations in LMICs, where two- or three-wheelers constitute a big proportion of vehicle fleets. In addition, considering the significant rise in the use of electric scooters, electric push scooters and other light mobility vehicles in urban environments, this could become an important regulatory gap in HICs too.

Both the road transport industry and independent scientists have tested the effectiveness of AVASs in making vulnerable road users aware of the presence of an EV. These studies involved different experiments to investigate the detectability levels of AVASs for different vehicles, speed, environmental conditions and type of road users (mainly pedestrians with or without sight impairment). The findings from the literature are not fully consistent with each other, especially in terms of levels of detectability of AVASs at speeds above 20 Km/h. However, **the literature seems to agree that, for travelling speeds below 20 Km/h, the addition of synthetic sound on EVs is effective in mitigating the road safety risk of quiet EVs for vulnerable road users.**

This brings the discussion back to the possible conflict between increasing road traffic safety and reducing noise annoyance. The problem of the additional environmental noise produced by AVASs has the potential to become an important one as the number of EVs on the road, especially in HIC cities, is steadily growing. This could also lead to a further two additional considerations: there could be a problem of acceptability by the public (and EV drivers) of the AVAS sound, and, to some extent more importantly, the detectability of an AVAS may be linked more to its sound type than to its volume.[34] **Although currently there is no evidence of the negative effects of AVASs on soundscapes and quality of life, it does not mean we should not expect some in the future. Indeed, common sense would dictate that we should be aiming to make cities safer and, at the same time, quieter, rather than one or the other.**

There are some suggestions from the literature of alternative and less noisy ways to alert vulnerable road users of the presence of EVs. One of the key alternative actions cited is the **raising of public awareness** (both of EV drivers and vulnerable road users) about the situations in which quiet EVs can represent a road safety risk. At the same time, this should be part of a more comprehensive approach to the problem through public policies fostering a **Safe System approach** to road safety. Finally, a possible countermeasure to the risk danger posed by quiet EVs could be the **autonomous driving system** installed on future EVs, which could be able to prevent possible collisions. However, until the technological advancement of road transport will be widespread enough, the use of AVASs is destined to be part of our cities' soundscape.

DISCUSSION: ELECTRIC VEHICLES AND ROAD SAFETY IN AFRICA AND SOUTH ASIA

As mentioned, unfortunately there is no primary study on the problem of quiet EVs in LICs and therefore this leaves a number of open questions: **should the introduction of AVAS-like regulations be a road safety priority in Africa and South Asia? If so, how should the approach to the problem in Africa and South Asia differ from the one in HICs?**

Differences in road users and behaviours

Urban roads in HICs and Africa and South Asia are populated with different users. Specifically, in an African or South Asian city, there usually are a **much higher number of pedestrians** as travel by foot is the main one in those regions. Moreover, contrary to what occurs in HICs, a significant number of **pedestrians occupy the road lanes** together with motorised vehicles. This is due to a lack of pavements, their poor conditions and/or obstacles on them. This lack of safe pedestrian space substantially increases their exposure to road traffic danger. In addition, **per capita motorised vehicle ownership between HICs and Africa and South Asia is also very different**, with a much higher proportion of motorised two-wheelers over cars in the latter compared to HICs, particularly in South Asia. **Three-wheelers and mini-bus taxies as well as a larger presence of animals on the road are also key characteristics of African and South Asian urban environments.**

Therefore, the key characteristics of African and South Asian road transport and mobility systems illustrated above make the road safety issues linked to quiet EVs potentially more significant than in HICs. Indeed, both the variety and ratio of vulnerable road users is greater in LIC cities than in HICs. In addition, there are other environmental and behavioural factors that increase their vulnerability, including a general higher level of environmental noise, a higher incidence of street crossing outside designated crossing areas, vendors at cross-roads and traffic lights, and the inconsistent application of traffic laws. Finally, it is important to note that in Africa and South Asia, currently the familiarity of vulnerable road users with EVs is close to non-existent, and they could be easily caught by surprise.

EV prospects in Africa and South Asia

The other key aspect to assess the importance of regulatory fixes to the problem of quiet EVs is to understand the forecasted size of the EV markets in Africa and South Asia. The IEA provided some hints of global EV prospects to 2030 in its "Global EV Outlook 2020".[4] According to that study, besides India and Pakistan, by 2030 Africa and South Asia will not be among the driving regions of global EV sales. However, **India and Pakistan** are two positive outliers among LMICs in Africa and South Asia. Both countries, in fact, **have launched ambitious national EV policies.** In 2019, Pakistan has approved the National Electric Vehicles Policy (NEVP) which aims to reach 30% of all passenger vehicles and heavy-duty trucks sales to be EVs in 2030 and 90% in 2040, and for two-, three-wheelers and buses 50% of new sales by 2030 and 90% by 2040.[40] India is also strongly pushing the transition to electric mobility. The country has had an EV policy since 2012[41], and in 2017, at the Eighth Clean Energy Ministerial joined other 10 likeminded governments in the EV30@30 campaign , which aims at achieving 30% of market share of EVs by 2030.[4] That plan is likely to be primarily powered by the sales of electric two- and three-wheelers as projected by the EV Global Outlook 2020.[4]

In conclusion, the projected EV penetration in Africa is not substantial, and their transport and mobility systems in the medium- to long-term are likely to be still dominated by ICEVs. On the contrary, in South Asia, it is foreseeable that by 2030, electric two- and three-wheelers will be part of the general transport landscape, particularly in India and Pakistan.

It is important to note that, while the prospects of increase in **EV penetration** are definitely positive in South Asia, their uptake **need to be accompanied by broader road safety considerations, including appropriate regulatory advances AVASs, as well as systemic changes towards Safe System Approach.**

CONCLUSIONS AND RECOMMENDATIONS

Based on all of the above, some conclusions can be drawn:

- **The road safety issue of quiet EVs can become an increasing problem in the future in South Asia, and to a much lesser extent in Africa, although there are currently far greater road safety and noise pollution problems in those regions.**
- **Because of the current high levels of noise pollution in LMIC cities, the effectiveness of the introduction of AVASs in EVs, in their current form, would likely be severely affected by it.**
- **Due to the current and projected future composition of national vehicle fleets in Africa and South Asia, any effective attempt to introduce AVAS-like regulations in those regions would have to include (and primarily target) electric two- and three-wheelers.**
- **There are peculiarities of African and South Asian transport and mobility systems that would reduce the effectiveness of the use of AVASs in reducing EVs' collisions with other vulnerable road users.**
- **Only a strategic and integrated approach to road safety in African and South Asian countries will carry substantial benefits, while the introduction of EV AVASs alone is likely to bring little improvement in road safety.**

In conclusion, for those countries that are planning for interventions in favour of the electrification of road transport, **the aim should not be to develop noisier AVASs to allow their detection in LMICs environment, but rather to work on reducing the maximum environmental noise that masks EV sound.** Furthermore, following the HICs' examples, **it is recommended that, together with comprehensive and enforceable road safety strategies, appropriate regulations on EVs and road safety are developed in LMICs.** In particular, AVASs should be regulated and installed also in EVs manufactured in or imported to LMICs, including Africa and South Asia. Finally, **the design and implementation of such regulatory framework should be accompanied by appropriate applied research.** In particular, in researching and writing this paper, the following research gaps relevant to the HVT programme and the design of effective actions against road safety issues of quiet EVs have been identified:

- **Research on the cost and benefits of adding AVASs in hybrid and electric vehicles in African and South Asian countries, including two- and three-wheelers**
- **Investigating the potential road safety risks of electric two- and/or three-wheelers in LMICs, particularly in South Asia**
- **Studies on the acoustic detectability of electric two- and three-wheelers to inform future regulations on AVASs in LMICs**
- **Research to define the acceptability levels and sound types of AVASs in African and South Asian urban contexts**
- **Specific studies linking road transport, noise pollution exposure and social inequalities in Africa and South Asia.**

CONTENTS

FIGURES

ABBREVIATIONS

A-S-I	Avoid-Shift-Improve Framework
AVAS	Acoustic Vehicle Alerting System
CO_2	Carbon Dioxide
DEFRA	UK Department for Environment, Food and Rural Affairs
EV	Electric Vehicle
FCDO	UK Foreign, Commonwealth and Development Office
GHG	Greenhouse Gas
HEV	Hybrid Electric Vehicle
HFCs	Hydrofluorocarbons
HICs	High-Income Countries
HVT	High Volume Transport Programme
ICEV	Internal Combustion Engine Vehicle
IEA	International Energy Agency
IMC	IMC Worldwide Ltd
LICs	Low-Income Countries
LMICs	Low- and Middle-Income Countries
MICs	Middle-Income Countries
NDC	Nationally Determined Contributions
NEVP	National Electric Vehicles Policy (Pakistan)
NHTSA	United States National Highway Traffic Safety Administration
NO_x	Nitrogen Oxides
O_3	Ozone
PEVMA	Pakistan Electric Vehicles Manufacturing Association
PIARC	World Road Association
PM	Particulate Matter
R&D	Research & Development
SLCPs	Short-Lived Climate Pollutants

SO_2	Sulphur Dioxide
TRL	Transport Research Laboratory (United Kingdom)
UNECE	United Nations Economic Commission for Europe
VTTI	Virginia Tech Transportation Institute
WHO	World Health Organisation

SECTION 1: INTRODUCTION

As sector with the fastest growing greenhouse gas (GHG) emissions, transport is at the forefront of the global low carbon transition. Transport accounted for a third of GHG emissions growth since 2010[1] and the International Transport Forum forecasts that global transport demand (both passenger and freight) will increase by threefold between 2015 and 2050.[2] Socio-economic dynamics in Low- and Middle-Income Countries (LMICs) in Asia and Africa, such as population growth, urbanisation, and middle-class development, are projected to be the key drivers of such dramatic change, and that is why another HVT paper[3] calls for African and Asian countries to increase the ambitiousness of transport targets and measures in their Nationally Determined Contributions (NDCs), in line with the Paris Agreement's goal of limiting global warming to below 1.5ºC.

One of the most widely known actions to decarbonise global transport is shifting to electric mobility, coupling it with national grids run by renewable energy. Although it is often described as the panacea for solving carbon-intensive transport systems, it has to be said that switching from Internal Combustion Engine Vehicles (ICEVs) to Electric Vehicles (EVs) can only be fully effective if it is inserted within a comprehensive sustainable transport strategy. This would entail a number of appropriate actions along the Avoid-Shift-Improve (A-S-I) Framework, which includes measures aiming at avoiding unnecessary transport, shifting to cleaner transport modes (EVs included), and improving vehicles' fuel economy, energy source, and size.[a] Nevertheless, shifting to EVs can not only be beneficial in addressing climate change, but it also brings about a number of co-benefits in other transport-related issues, such as reduced air and noise pollution.

Indeed, should the general urban population use EVs instead of ICEVs to go from A to B, our cities would sound very different, probably much quieter than today. This is not a science-fiction scenario. EVs are attracting global investments and, to date, 17 countries have pledged 100% zero-emission vehicle targets or the phase-out of ICEVs by 2050 and the International Energy Agency (IEA) projects that EV global car stock share will range between 7% and 30% by 2030.[4] Therefore, EVs are likely to be part of our normal urban landscapes in a fairly near future.

Although noise pollution is a serious problem affecting global urban environments and disproportionally those in LMICs, the fact that EVs are substantially noiseless at low speeds can pose some serious road safety issues. In fact, there are a number of potential scenarios that would see quiet EVs increase the risk of collision with pedestrians, cyclists, people with sight disabilities and other city users.

This Insight Paper seeks to discuss the links between two key issues of today's global transport: electric vehicles and road safety. In particular, the document revolves around the key question of **how to find the balance between tackling climate change, air pollution and noise pollution on the one hand, and improving road safety on the other hand.** HVT's preliminary research shows that this is an under-researched topic, with no studies found in this area relating to Low Income Countries (LICs). Therefore, examples from High Income Countries (HICs) are used in this paper as the basis to discuss the possible impact on road safety of EV penetration in LMICs in Africa and South Asia, as well as possible solutions and research gaps.

The paper begins by putting into perspective the different issues linked to EVs treated in this paper, that is road safety, air pollution and noise pollution (Section 2:). The following section illustrates the road safety problems of quiet EVs and the regulatory solutions adopted in HICs (Section 1:). In Section 4: , the paper discusses the possible road safety implications of quiet EVs in Africa and South Asia. Finally, some conclusions and recommendations are provided in Section 5: . Section 5:

[a] For more information on the A-S-I Framework and concrete sustainable transport measures see https://www.transformative-mobility.org/assets/publications/ASI_TUMI_SUTP_iNUA_No-9_April-2019.pdf.

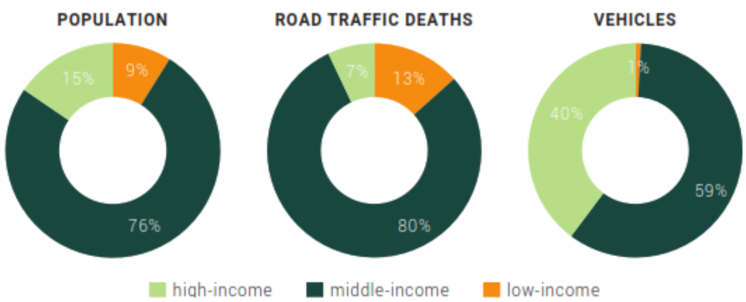
SECTION 2: BRIEF REVIEW OF THE IMPACT OF ROAD SAFETY, AIR POLLUTION AND NOISE POLLUTION ON HUMAN HEALTH

1. Road safety

According to the World Health Organisation (WHO), road traffic is the 8th leading cause of death (and 1st among non-health causes) for people of all ages and causes an estimated 1.4 million deaths each year.[6] In addition, between 20 and 50 million people every year suffer non-fatal injuries due to road traffic conflicts, which lead to millions of disabilities.[7]

Unsurprisingly, due to poor health and safety, road conditions, and other systemic problems, the large majority of road traffic related deaths occur in LMICs. It is estimated that over 90% of road fatalities occur in LMICs, even though these countries account for about 60% of world's vehicle fleet. Particularly concerning is the road safety situation in LICs. Indeed, if the proportions of global registered vehicles and road traffic fatalities is considered, LICs sees a ratio of 13 percentage points of deaths per 1% of vehicles share, compared to 1.35 and 0.175 percentage points of deaths per 1% of registered vehicle share in MICs and HICs respectively (see Figure 1). To put it into perspective, the risk of death due to road traffic injuries is more than three times higher in LICs (27.5 deaths per 100,000 population) than in HICs (8.3 deaths per 100,000 population).[6]

Figure 1. Proportion of population, road traffic deaths, and registered motor vehicles by country income category*, 2016[6]



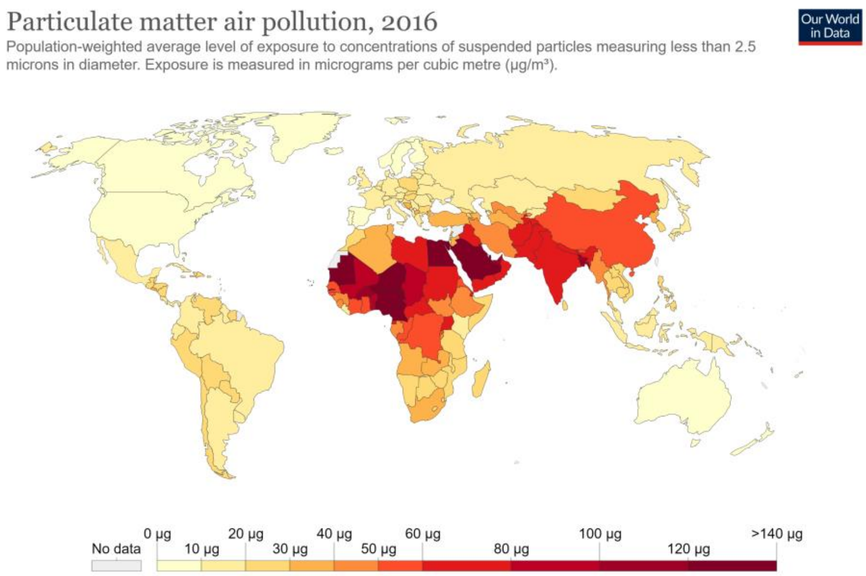
2. Outdoor air pollution

Outdoor or ambient air pollution has been a substantial health hazard for modern societies since the beginning of the industrial revolution. Indeed, air pollution causes or exacerbates numerous serious human pathologies, such as cardiovascular diseases, respiratory diseases and cancers, which can lead to high burdens for health systems and deaths. The WHO reports that ambient air pollution was linked to 4.2 million premature deaths in 2016, affecting both urban and rural areas in high-, medium- and low-income countries.[8] Nevertheless, it is estimated that **9 out of 10 of annual fatalities linked to outdoor air pollution occur in LMICs**.[10] Figure 2 shows how Africa and South Asia are the most exposed world regions to high concentrations of fine particulate matter (PM), which is the leading global health hazard air pollutant.

There are many anthropogenic activities which cause ambient air pollution, such as fuel combustion from motor vehicles, heat and electricity generation, industrial processes, waste management, some agricultural practices, and some residential activities, including heating and cooking. These activities emit different pollutants that ultimately may end up in people's lungs. Evidence show that the main pollutants in terms of health risk are: PM, ozone (O_3), nitrogen oxides (NO_x) and sulphur dioxide (SO_2).[9]

In addition of being a serious health hazard, some outdoor air pollutants are also potent GHGs, causing climate change. Although carbon dioxide (CO_2) is the most commonly known GHG as it has been increasing exponentially since pre-industrial time and can persist in the atmosphere for centuries, there are also other potent GHGs linked to outdoor air pollution. This is the case of short-lived climate pollutants (SLCPs), which, despite persisting in the atmosphere from anything between days to a decade, they can be significant for both their health and climate change related consequences. Black carbon (a component of PM), ozone, hydrofluorocarbons (HFCs) and methane are all SLCPs. There is strong evidence that promoting the mitigation of SLCPs is not only an important way to combat climate change, but can also bring about important co-benefits in terms of health, environmental change, and noise pollution reduction.[10]

Figure 2. Exposure to $PM_{2.5}$ by country in 2016[11]



Although, road transport is not the only source of outdoor air pollution, it is certainly one of the most important. The European Environment Agency points out that more than 40% of both NO_x and $PM_{2.5}$ in the European Union come from transport.[12] The UK Department for Environment, Food and Rural Affairs (DEFRA) identifies road traffic emissions as the current "major threat to clean air", explaining that not only ICEVs account for a large proportion of different air pollutants, but also, they are able to spread them for long distances, contrarily to what happens with more stationary sources, such as power plants.[13]

Indeed, there is scientific evidence confirming the ability of road traffic regulations[14] and the switch from ICEVs to EVs (coupled with a cleaner electricity mix)[15] of strongly reducing outdoor air pollution.

3. Noise pollution

Environmental noise pollution, i.e. unwanted disturbance provoked by noise from outdoor surroundings, is the other key form of environmental pollution related to road transport. Motorised transport in urban settings is the main source of noise pollution and the problem is in expansion, driven by socio-economical dynamics, such as population growth, urbanisation and technological development.[16]

Noise pollution is a serious health hazard. The WHO estimates that every year 1 million "health years"[b] of life is lost in Western Europe due to traffic noise.[17] The WHO categorises the adverse health effects of noise pollution under seven categories[18]:

- Hearing impairment
- Negative social behaviour and annoyance
- Interference with spoken communication
- Sleep disturbances, cardiovascular disturbance
- Mental health issues
- Performance reduction.

Jariwala et al., after a comprehensive literature review of the impact of noise on human health, state that "[t]he potential health effects of noise pollution are numerous, pervasive, persistent, medically and socially

[b] I.e. Time lost due to premature mortality.

significant. Noise produces direct and cumulative adverse effects that impair health and that degrade residential, social and working environment with corresponding real (economic) and intangible (well-being) losses.[19] Noise pollution does not affect only human life, as it was shown how man-made noise can have detrimental effects on biodiversity too, for example by masking and inhibiting animal sounds and/or hearing, thus affecting communication, reproduction and use of space.[19]

Unsurprisingly, there is scientific evidence that the problem of noise pollution in LMICs is very serious. For instance, a comparative study from the University of York gathered information about exposure to environmental noise levels from cities in 28 LMICs.[16] The study concluded that in all cities, noise levels substantially exceeded the WHO health guidelines and that, despite all 28 countries have passed laws defining permissible noise limits, the exposure to harmful noise levels has not improved in the last decade because of poor enforcement.

Research also shows a positive relationship between exposure to noise pollution and social inequalities indicators. For example, a meta-analysis published in the International Journal of Environmental Research and Public Health found that, in the WHO European Region, a trend can be seen between general indices of socio-economic deprivation and levels of exposure to noise pollution.[20] However, the authors of the study pointed out that the number of reviewed studies was too low to draw a definitive conclusion.

Research gap identified: A research gap potentially interesting for the Applied Research Programme on High Volume Transport (HVT) has been identified in specific studies linking road transport, noise pollution exposure and social inequalities in Africa and South Asia.

SECTION 3: ELECTRIC VEHICLES AND ROAD SAFETY IN HIGH INCOME COUNTRIES

1. The problem of quiet electric and hybrid electric vehicles for road safety

As explained above, there is evidence showing that the urban populations in LMICs are consistently exposed to noise levels exceeding the WHO health guidelines[9], which sets the limit for noise in outdoor living areas at 50-55 dB. Prolonged exposure to noise levels above those can have critical health effects, some of which were described in Section 2: . However, noise pollution is not just a LMIC problem, but a global one. For example, a recent report from the European Environment Agency[22] estimates that 113 million people in the European Union are affected by road traffic noise levels at or above 55 dB during the day-evening-night period.

Generally, the noise of passing vehicles is composed of the noise of the engine or powertrain, and the noise of the tyres on the road. However, there is an important difference on this aspect between ICEVs and EVs (including hybrid electric vehicles (HEVs)): **at low speed, while for ICEVs the dominant source of noise is the powertrain, for EVs the powertrain noise is extremely low.**

Although this characteristic makes EVs very effective in mitigating noise pollution, the absence of a recognisable audible presence can create a road safety hazard in low speed driving conditions, which are most likely to occur in urban environments, the areas where the risk of collision with vulnerable road users[c] is higher. Therefore, as the Road Safety Observatory points out, this highlights an important trade-off for policy-makers between "optimal noise levels for health and social well-being and optimal noise for the safety of pedestrians, cyclists and other road users who rely on vehicle noise as a warning sound."[23]

In the literature, there is contrasting evidence that EVs actually cause more collisions with vulnerable road users than ICEVs. For instance, the United States National Highway Traffic Safety Administration (NHTSA) in a 2009 study found that the collision rate of HEVs with pedestrians and cyclists whilst travelling at low speed or manoeuvring was double than ICEVs.[24] At the same time, the study highlights that the results should be treated with caution, due to limited dataset. In addition, an empirical study from The TAS Partnership, which unfortunately could not be reviewed by the author, found that EVs are 40% more likely to hit pedestrians than ICEVs.[5] A different conclusion was reached by a 2010 study by the Transport Research Laboratory (TRL) which, based on in-depth literature, standards and legislation review, found no concrete evidence of a higher road safety risk posed by EVs to vulnerable road users. [25] However, the study does point out that "very little research has been published on the risk presented by quiet vehicles". Therefore, what seems to emerge is that **further research is needed to determine the risk of quiet EVs to vulnerable road users.**

Although currently there seems to be no hard evidence to confirm the argument that quiet EVs cause more collisions with vulnerable road users than ICEVs, it is reasonable to expect that, with the substantial projected increase in EVs in circulation, more evidence (proving or disproving the argument) will come to light. For example, a 2015 online poll among 2,228 adults, resident in the UK, revealed that about three quarter of respondents agreed that quiet EVs represented a road safety risk for pedestrians with sight impairment (76%), elderlies (78%) and children (75%).[5] Similarly, a recent article from researchers of the University of Malaga, Spain, studied the risk perception of 95 experienced EV drivers from Malaga.[26] The conclusions from the study tend to confirm that quiet EVs do pose a risk for vulnerable road users. In fact, although none of the interviewed EV drivers reported to have been involved in a collision due to the low noise of their EV, 62% of the sample described situations of risk or incidents. In particular, from the results by the latter sample, most drivers confirmed that the risk events occurred while travelling below 30 Km/h. Other situations of road safety risk reported included: traffic lights or turning, overtaking, and moving the vehicle

[c] In this paper, the category of "vulnerable road users" is created and it includes pedestrians and users of "light mobility vehicles" such as bicycles, push scooters, balance boards, skateboards etc. These are road users for whom the sense of hearing plays a substantial role in their ability to detect other road users or danger. The author acknowledges the potential contradiction of the term in that, in this paper, vulnerable road users would include electric versions of light mobility vehicles, such as electric bikes and scooters, which are themselves quiet EVs and, according to the circumstances, could be the ones posing safety risks to other vulnerable road users. Nevertheless, if this caveat is born in mind, the term is sufficiently clear and it has been used throughout the paper. The term is meant to be used for this paper only, i.e. not for broader use.

from a stationary position. Interestingly, many of the EV drivers interviewed reported that they are conscious that other road users may not hear them at low speeds and therefore they pay particular attention in those key risk situations.

2. Regulatory solutions

The road transport regulators in HICs have been addressing the problem of quiet EVs with the addition of synthetic noise or EV Acoustic Vehicle Alerting Systems (AVASs). In the European Union, including the UK, EU Regulation 2017/1576 mandates that AVASs must be installed on all new types of pure electric and hybrid vehicles effective on 1 July 2019, while AVASs will be obligatory on all sold new EVs and HEVs from 1 July 2021.[27] The AVASs will have to generate sound when the vehicle is circulating at a speed of up to 20 Km/h and when reversing. The EU Regulation also provides some specifications on the acoustic characteristics of the AVASs, the sound of which must:

- Be continuous and "be easily indicative of the vehicle behaviour, for example, through the automatic variation of sound level or characteristics in synchronisation with vehicle speed"
- Be similar to the sound of an ICEV of the same category
- Not exceed the sound level of a similar ICEV operating under the same conditions of the EV.

In the United States, the NHTSA has acted in a similar manner with the Federal Motor Vehicle Safety Standard No. 141, which requires all newly produced EVs and HEVs weighting less than 10,000 pounds (~4,535 Kg) to be outfitted by 1 September 2020 with a "pedestrian alerting system" (the equivalent of the AVAS) when travelling at a speed below 19 MPH (~30 Km/h).[28]

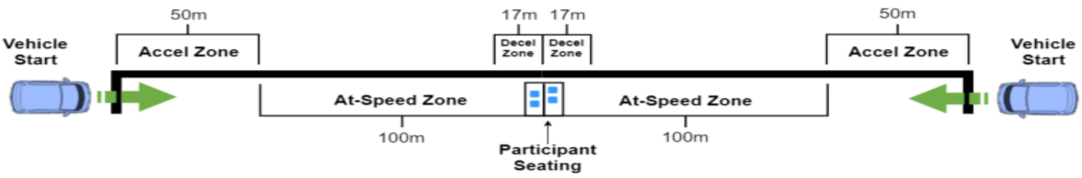
In Asia, Japan and China have both introduced standards for AVASs. China is reported to intend to make the standard GB/T 37153-2018 "Electric car low speed tone" mandatory in the near future.[29] This standard basically mirrors the United Nations Economic Commission for Europe (UNECE) Regulation 138, which is the one also reflected in the EU Regulation on AVASs. As Japanese car makers have been the pioneers of HEVs, the Japanese government has been aware of the road safety risk of quiet EVs for a long time. In fact, back in 2009, Japan created a "Committee for the Consideration of Countermeasures Regarding Quiet Hybrid and Other Vehicles", which develop guidelines for AVASs on EVs, HEVs, and fuel cell vehicles adopted in 2010. Although the Japanese guidelines are voluntary in nature, they are reported to have been used in the market (for instance by Toyota on the Prius) since 2010.[30]

One important limitation of all these regulatory instruments is that they do not cover requirements for two- or three-wheelers. This exclusion can be substantial in curtailing the effectiveness of similar regulations in LMICs, where two- or three-wheelers constitute a big proportion of vehicle fleets. In addition, considering the significant rise in the use of electric scooters, electric push scooters and other light mobility vehicles in urban environments, this could become an important regulatory gap in HICs too. The main reason cited by the NHTSA for excluding electric two-wheelers from the addition of AVASs is that "we currently do not have enough information to determine whether the light vehicle acoustic requirements or the crossover speed in this final rule are appropriate for electric motorcycles."[31] Furthermore, the studies previously cited that researched the increased road safety risk posed by quiet EVs have only focused on cars.

Research gap identified: An interesting research topic for HVT could be to study the acoustic detectability of electric two- and three-wheelers to inform future regulations on AVASs in LICs.

Both the road transport industry and independent scientists have tested the effectiveness of AVASs in making vulnerable road users aware of the presence of an EV. For instance, the Virginia Tech Transportation Institute (VTTI) recently conducted an evaluation of EV AVAS's detectability.[32]

Figure 3: Scale test environment of VTTI testing of vehicle noise detectability[32]



The experiment involved testing at what distance a random sample of 16 participants standing on the side of a road would detect the presence of a vehicle coming at different speeds (see **Error! Reference source not found.**). The test included both an EV (Chevrolet Volt) with and without AVASs installed and compared the results with an ICEV, a HEV, and EVs with and without AVAS from a previous study conducted in a similar environment by the same authors. The results showed that with the latest generation of AVASs, the average detectability of EVs at a 20 Km/h steady speed was 73.4m, while for an EV without AVAS, its average detectability was reduced to 20.1m. When the approaching speed was reduced to 10 Km/h, the detectability of the EV with AVAS was 29.7m and the one of the EV without AVAS was only 7.0m. In comparison, the ICEV from the past study was averagely detected at 33.7m and 20.7m respectively with an approaching speed of 20 Km/h and 10 Km/h. According to the results, the effectiveness of the last generation AVAS in improving the EV detectability is impressively high, increasing an EV detectability distance of 3.6 and 4.2 times compared to an EV without AVAS, respectively at 20 Km/h and 10 Km/h approaching speed.

However, other studies have reached different conclusions. For example, another study compared different models of EVs by measuring the sound pressure levels when they were at 7.5m from the detection point, while travelling at 10, 20, and 30 Km/h.[33] The experiment showed how the effectiveness of the AVAS was usually significant at a speed of 10 Km/h, much less significant but still present at 20 Km/h, and had almost no effect when driving past 30 Km/h. A similar conclusion was reached by researchers from a Norwegian independent research organisation who conducted a side road detectability test similar to the one from VTTI, with the difference that they only selected participants with sight impairment or blind. They found that at a speed of 20 Km/h, the AVAS had no influence on the distance of EV detection. [34]

Furthermore, evidence shows that the warning effect of AVASs can vary substantially from one EV model to another. For instance, the German study described above[33] found that because manufacturers design AVASs differently, sound pressure levels among the different EVs tested varied between 1 to 11dB at a 10 Km/h speed to 0 to 5dB at a 20 Km/h. The same study showed that even the AVAS's sound pressure level of the same EV sometimes resulted in differences depending on whether the passage was coming from the left or from the right.[33]

In conclusion, the literature seems to agree that, for travelling speeds below 20 Km/h, the addition of synthetic sound on EVs is effective in mitigating the road safety risk of quiet EVs for vulnerable road users.

This brings the discussion back to the possible conflict between increasing road traffic safety and reducing noise annoyance. The problem of the additional environmental noise produced by AVASs has the potential to become an important one as the number of EVs on the road, especially in HIC cities, is steadily growing. In addition, studies show that, generally, sounds are perceived as disturbing and annoying when the receiver is not used to it. For example, research found that the sound of a passing-by EV with AVAS was considerably perceived as more annoying than the one of a combustion engine car, and concluded that the main reason for it was the level of familiarity to the sound by the participants.[33]

This could also lead to a further two additional considerations: there could be a problem of acceptability by the public (and EV drivers) of the AVAS sound, and, to some extent more importantly, the detectability of an AVAS may be linked more to its sound type than to its volume.[33] To these issues, car manufacturers have responded by focusing their Research & Development (R&D) into the development of AVASs on finding the right sound for their EVs. When you add a marketing perspective to it, it appears likely that in the future, sound may become as much as a signature characteristic of an EV as its aesthetics. There are reports that major automakers have been receiving professional consulting services by musicians and DJs as "sound experts" to work with their teams in designing their AVASs.[35]

As the number of cars with AVASs on the roads is still very low, it appears that there is not enough empirical evidence to determine their levels of acceptance and annoyance by the public. A German study specifically investigating the possible influence of EV AVASs on urban soundscape reached the same conclusion.[33] The study underscored the fact that soundscapes analyses are directly linked to the subject and its surrounding environment and called for more soundscape studies on the acceptability of EV AVASs in actual urban contexts. The researchers suggested that limited traffic zones in cities where only EVs are allowed to circulate could be a good option for testing the acceptability of AVASs in an urban environment, without mixing them with the noise of combustion engines.

Research gap identified: HVT could be interested in supporting soundscape research to define the acceptability levels of AVASs in African and South Asian urban contexts.

Although currently there is no evidence of the negative effects of AVASs on soundscapes and quality of life, it does not mean we should not expect some in the future. Indeed, common sense would dictate that we should be aiming to make cities safer and, at the same time, quieter, rather than one or the other. There are some suggestions from the literature of alternative and less noisy ways to alert vulnerable road users of the presence of EVs. One of the key alternative actions cited is the **raising of public awareness** (both of EV drivers and vulnerable road users) about the situations in which quiet EVs can represent a road safety risk. As an increasing number of EVs are introduced in urban environments, it is important that all road users are informed of their benefits as well as potential risks. This should be part of a more comprehensive approach to the problem through public policies fostering a **Safe System approach** to road safety. The Safe System approach, as described by the World Road Association (PIARC), involves four main design elements:

- "Safe roads and roadsides – that are predictable and forgiving of mistakes
- Safe speeds – travel speeds that suit the function and level of safety of the road
- Safe vehicles – that prevent crashes and protect road users, including occupants, pedestrians and cyclists, in the event of a crash
- Safe road users – road users that are alert and unimpaired, and who comply with road rules."[41]

Moreover, a possible countermeasure to the risk danger posed by quiet EVs could be the **autonomous driving system** installed on future EVs, which could be able to prevent possible collisions. As self-driving or electronically assisted driving vehicles are becoming more common, it is not hard to think that the need for AVASs may disappear in the future as the vehicles themselves will be able to avoid the collisions.

However, until the technological advancement of road transport will be widespread enough, the use of AVASs is destined to be part of our cities' soundscape.

SECTION 4: DISCUSSION: ELECTRIC VEHICLES AND ROAD SAFETY IN AFRICA AND SOUTH ASIA

As mentioned, unfortunately there is no primary study on the problem of quiet EVs in LICs and therefore this leaves a number of open questions: **should the introduction of AVAS-like regulations be a road safety priority in Africa and South Asia? If so, how should the approach to the problem in Africa and South Asia differ from the one in HICs?**

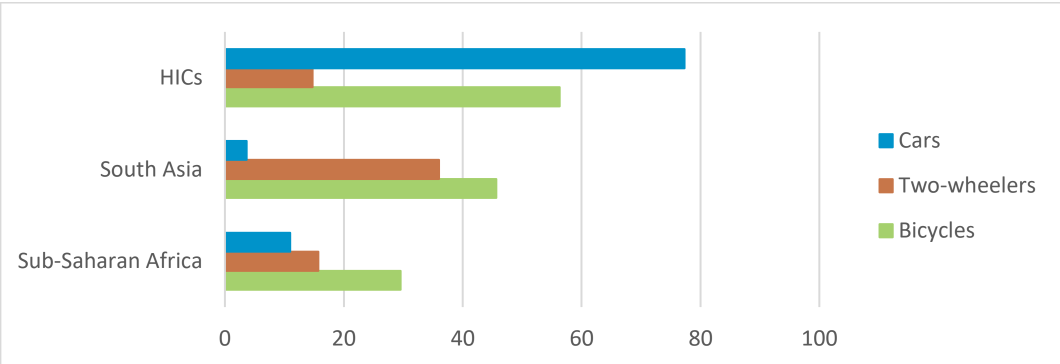
In order to answer these questions, this section discusses the key characteristics of urban transport systems, and the prospect of the electrification of road transport in Africa and South Asia compared to HICs.

1. Differences in road users and behaviours

Urban roads in HICs and Africa and South Asia are populated with different users. For example, the typical road landscape in a European or North American city would see the prevalent presence of private and commercial cars of different sizes, buses and trams as the predominant means of road public transport, private motorbikes and scooters, cyclists, and pedestrians. The latter sometimes would have dedicated cycling lanes, while generally, pedestrians would be physically separated from road traffic by pavements.

In contrast, in a metropolis in Sub-Saharan Africa or South Asia we would likely see something very different. The first difference that would be evident is the **much higher number of pedestrians** on the roads. Walking is an essential part of life in African and South Asian cities, much more than it is in HICs. For instance, in African megacities such as Dakar, Lagos or Accra, more than 70% of the population usually travel by foot.[36] In addition, and contrary to what occurs in HICs, a significant number of pedestrians occupy the road lanes together with motorised vehicles. This is due to a lack of pavements, their poor conditions and/or obstacles on them. This lack of safe pedestrian space substantially increases their exposure to road traffic danger. The WHO[7] estimates that about 40% of all road traffic deaths in Africa are pedestrians compared to a 23% world average.

Figure 4. Percentage of households declaring to own a vehicle[37]



Per capita motorised vehicle ownership between HICs and Africa and South Asia is also very different. For example, the Pew Charitable Trust in its 2014 Spring Pew Global Attitudes Survey[37] asked over 48,000 households in 44 countries[d] whether they owned a car, a two-wheeler (motorbike and scooter), and a bicycle. Relevant results are reported in Figure 4. It can be seen that the roads in HICs are dominated by cars, while **car ownership is much lower in Sub-Saharan Africa (11%) and even lower in South Asia (4%)**. If South Africa (31%) and Nigeria (18%) are excluded from the sample, the car ownership rate of Sub-Saharan Africa goes down to 6%. At the same time, **South Asian families are about twice as likely to own a motorised two-**

[d] The relevant countries included in the survey are: India, Pakistan and Bangladesh in South Asia; Ghana, Kenya, Nigeria, Senegal, South Africa, Tanzania and Uganda in Sub-Saharan Africa.

wheeler (36%) than families in Sub-Saharan Africa (16%) and HICs (15%). Indeed, this is consistent with the traffic scene in a South Asian megacity, where two- (and even more often three-wheelers) are not only used as private transport vehicles, but also as taxies or sometimes even freight vehicles. This is also common in Africa, where motorbike taxies take different names in different regions, such as "boda bodas" in East Africa and "okadas" in West Africa. Mini-bus taxies are also a key characteristic of African urban traffic, which instead are rarely found in HIC cities.

Busy street in Dhaka, Bangladesh
Photo by Niloy Biswas | Source: Unsplash.com

Furthermore, in Africa and South Asia there is a larger presence of animals on the road than in HICs. Animal carriages, for instance, are often seen on both African and South Asian streets, pulled by cows, donkeys or horses, and used for carrying people or goods.[37] Street dogs are also common in LICs and they are often found on the road lanes in cities.

The key characteristics of African and South Asian road transport and mobility systems illustrated above make the road safety issues linked to quiet EVs potentially more significant than in HICs.

Indeed, both the variety and ratio of vulnerable road users is greater in LIC cities than in HICs. African and South Asian city roads are populated with a high number of pedestrians of all ages, animals, slow bicycles and carriages, all of which could be at risk to be hit by silent EVs. **In addition, there are other environmental and behavioural factors that increase their vulnerability.** As mentioned in Section 2: , the average level of **environmental noise in LMIC cities is generally very high**, which would reduce the likelihood of hearing a silent EV, even with the addition of an AVAS. This may be emphasised in places like Africa and South Asia, where the **familiarity of vulnerable road users with EVs is close to non-existent**, and they could be easily caught by surprise. Finally, there are a number of cultural and behavioural aspects of African and South Asian road users that could create risky encounters with silent EVs. Among those we can include a **higher incidence of street crossing outside designated crossing areas, vendors at cross-roads and traffic lights, and the inconsistent application of traffic laws.**

2. EV prospects in Africa and South Asia

The other key aspect to assess the importance of regulatory fixes to the problem of quiet EVs is to understand the forecasted size of the EV markets in Africa and South Asia. The IEA provided some hints of global EV prospects to 2030 in its "Global EV Outlook 2020".[4] According to that study, **besides India and Pakistan, by 2030 Africa and South Asia will not be among the driving regions of global EV sales.** This is not surprising as EVs are on average more expensive than ICEVs, and purchasing a new EV is something that is most likely only accessible to high net worth individuals in those regions. In addition, charging infrastructure and other supporting services, such as specialised mechanics and part dealers, are still broadly lacking in both regions.

As said, India and Pakistan are two positive outliers among LMICs in Africa and South Asia. Both countries, in fact, have launched ambitious national EV policies. In 2019, **Pakistan** has approved the National Electric Vehicles Policy (NEVP) which aims to reach 30% of all passenger vehicles and heavy-duty trucks sales to be EVs in 2030 and 90% in 2040, and for two-, three-wheelers and buses 50% of new sales by 2030 and 90% by 2040.[38] According to the International Council on Clean Transportation, the NEVP is driven by Pakistan's ambitions to strongly act against climate change and air pollution, but also to boost its EV manufacturing sector, which recently saw its five domestic producers join the Pakistan Electric Vehicles Manufacturing Association (PEVMA).[38]

India is also strongly pushing the transition to electric mobility. The country has had an EV policy since 2012[39], and in 2017, at the Eighth Clean Energy Ministerial joined other 10 likeminded governments in the EV30@30 campaign[e], which aims at achieving 30% of market share of EVs by 2030.[4] That plan is likely to be primarily powered by the sales of electric two- and three-wheelers as projected by the EV Global Outlook 2020.[4] In 2019, the national government announced its intention to have only electric three-wheelers operating in the country by 2023, and only electric two-wheelers by 2025[40], although there is no current policy to back that target up. It is estimated that about 20% of GHG and 30% of PM emissions in India come from motorised two-wheelers[4], which means that the shift to e-motorbikes and scooters could be an extremely effective way to tackle air pollution, climate change and noise pollution at the same time. The other driver for India's transition to EVs is economic, as it is among the top 5 global automotive manufacturers and is planning to strengthen its domestic EV industry. Both the national and state governments such as Delhi, Tamil Nadu, Karnataka, Maharashtra, and Uttarakhand have EV policies and incentives in place.

In conclusion, the projected EV penetration in Africa is not substantial, and their transport and mobility systems in the medium- to long-term are likely to be still dominated by ICEVs. On the contrary, in South Asia, it is foreseeable that by 2030, electric two- and three-wheelers will be part of the general transport landscape, particularly in India and Pakistan.

It is important to note that, while the prospects of increase in EV penetration are definitely positive in South Asia, their uptake need to be accompanied by broader road safety considerations, including appropriate regulatory advances AVASs, as well as systemic changes towards Safe System Approach.

Research gap identified: A lack of studies to investigate the potential road safety risks of electric two- and/or three-wheelers in LMICs, particularly in South Asia, was identified.

[e] Eleven countries endorsed the campaign: Canada, China, Finland, France, India, Japan, Mexico, Netherlands, Norway, Sweden and the United Kingdom.

SECTION 5: CONCLUSIONS AND RECOMMENDATIONS

In the previous sections, the relevant issues around EVs this paper has been focusing on, namely GHG emissions, outdoor air pollution, noise pollution, and road safety were presented. This was followed by the illustration and discussion of the road safety problems of quiet EVs in HICs and the regulatory solutions that have been put in place to address them. Finally, the problem was framed in the context of the key differences in transport and mobility systems and future EV prospects between HICs and Africa and South Asia. Based on all of the above, some conclusions can be drawn:

- **The road safety issue of quiet EVs can become an increasing problem in the future in South Asia, and to a much lesser extent in Africa, although there are currently far greater road safety and noise pollution problems in those regions.**
- **Because of the current high levels of noise pollution in LMIC cities, the effectiveness of the introduction of AVASs in EVs, in their current form, would likely be severely affected by it.**
- **Due to the current and projected future composition of national vehicle fleets in Africa and South Asia, any effective attempt to introduce AVAS-like regulations in those regions would have to include (and primarily target) electric two- and three-wheelers.**
- **There are peculiarities of African and South Asian transport and mobility systems that would reduce the effectiveness of the use of AVASs in reducing EVs' collisions with other vulnerable road users.**
- **Only a strategic and integrated approach to road safety in African and South Asian countries will carry substantial benefits, while the introduction of EV AVASs alone is likely to bring little improvement in road safety.**

In conclusion, for those countries that are planning for interventions in favour of the electrification of road transport, it will be important to accompany them with policies, and most of all their effective enforcement, against noise pollution. Indeed, **the aim should not be to develop noisier AVASs to allow their detection in LMICs environment, but rather to work on reducing the maximum environmental noise that masks EV sound.**

Furthermore, following the HICs' examples, **it is recommended that, together with comprehensive and enforceable road safety strategies, appropriate regulations on EVs and road safety are developed in LMICs.** In particular, AVASs should be regulated and installed also in EVs manufactured in or imported to LMICs, including Africa and South Asia.

The design and implementation of such regulatory framework should be accompanied by appropriate applied research. In particular, in researching and writing this paper, the following research gaps relevant to the HVT programme and the design of effective actions against road safety issues of quiet EVs have been identified:

- Research on the cost and benefits of adding AVASs in hybrid and electric vehicles in African and South Asian countries, including two- and three-wheelers
- Investigating the potential road safety risks of electric two- and/or three-wheelers in LMICs, particularly in South Asia
- Studies on the acoustic detectability of electric two- and three-wheelers to inform future regulations on AVASs in LMICs
- Research to define the acceptability levels and sound types of AVASs in African and South Asian urban contexts
- Specific studies linking road transport, noise pollution exposure and social inequalities in Africa and South Asia.

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