Study on the impact of automotive noise and vibration on human health and environment

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Abstract. This paper exposes the initial part of a larger research on the impact of the automotive on human health and the quality of life and environment. After a brief introduction on the need for responsible and sustainable approaches and few questions on the subject, some considerations and statistical data are presented, based on a study of the literature on the impact of road traffic and vehicles noise and vibration on people's comfort and health and their quality of life. The research results show, based on official statistics, the significant harmful impact of noise and vibration from motor vehicles and road transport on people's health and quality of life, especially in urban areas during the day. Also, the significant increase in the number of electric and hybrid vehicles from one year to another, a reality and a necessity nowadays, and the awareness that electric vehicles are not perfectly quiet and comfortable, open new research opportunities and require the development of new standards, materials, tools, equipment and test methods in the field of NVH, in a sustained synergistic approach from all stakeholders, to meet the needs and demands of today's consumers, and to comply with existing regulations and standards on environmental protection and sustainable development.

1. Introduction

In today's context, when it is increasingly felt, in various forms, the negative impact of a flawed economic and industrial development, focused on profit only, expressions such as sustainable development, sustainability, quality of life and environmental protection are increasingly present in our daily lives. On the other hand, we like to travel more and more, we are more and more comfortable and we use our personal or business car even for very short trips. We are, we can say, in a dilemma: we are aware that measures need to be taken, but, it seems, not responsible enough to really act on this, both personally and institutionally. Yes, there is awareness, commitments, declarations, policies, regulations, action plans, examples of best practices, but we always have a problem in meeting the deadlines, being stopped or turned back by various obstacles.

On a personal level, today, more than ever, we want to be cool, fashionable, trendy... We choose, not always what is best for us, but we choose according to the choices of others. To be and to have the same or even more, better, more differently than others! We are, it seems, in a permanent competition, with ourselves and with others, but at what price?

In all this context, choosing an electric car seems to be a more than appropriate option, in many ways. It's modern, smart, trendy, quiet, comfortable and green. All in one! Is really true?

Is the electric car the best choice for us?

Is the electric car less polluting than the traditional combustion car?

Is the electric car quieter, more comfortable and safer for the driver, passengers and other road users?

These are questions that cannot yet be answered with certainty, there are multiple answers, different, even from one extreme to another, more or less argued. They are topical questions, to which the right answer is still being sought. A comprehensive review on electric vehicle advancements, barriers, and potential is presented in [1], the results showing the need for collaborative efforts between all stakeholders, to responde the new challenges of sustainable development of the automotive industry and transport system.

We are also looking for answers. In this investigation, we set out to try to find the most appropriate answers on the negative impact of vehicle noise and vibration on quality of life and the environment, in a somewhat comparative approach to electric versus traditional cars.

2. Road traffic noise considerations

After air pollution, which is also largely due to road traffic, one of the biggest threats to the environment and to the health of the population in Europe and beyond is noise pollution, especially environmental noise from transport activities, with road transport being the most significant. In fact, in Western Europe, transport noise is considered the second most important cause of environmental damage causing major health problems after fine particle pollution. Therefore, environmental noise is today a significant concern for citizens, institutions and policy makers.

As early as 2002, the Environmental Noise Directive (END) was introduced at EU level, making it mandatory for Member States to assess environmental noise and monitor the effectiveness of emission controls. Two key indicators were introduced, for annoyance and sleep disturbance, which, if exceeded, would require action plans to reduce exposure. Also, at WHO level, exposure limits to road traffic noise of up to 53dB day-evening-night and 45dB night-time are recommended to avoid negative health consequences [2].

According END, “environmental noise shall mean unwanted or harmful outdoor sound created by human activities, including noise emitted by means of transport, road traffic, rail traffic, air traffic, and from sites of industrial activity such as those defined in Annex I to Council Directive 96/61/EC of 24 September 1996 concerning integrated pollution prevention and control” [3].

To mitigate the damaging effect of noise pollution, the European Commission, in its vision to reduce pollution to zero by 2050, has set as a key objective, significant reducing environmental noise at European level for the next period. Thus, according to the EU legislation, the European Green Deal “Striving to be the first climate-neutral continent” and the EU Action Plan "Towards a Zero Pollution for Air, Water and Soil", at EU level, the share of people chronically disturbed by transport noise should be reduced by 30% by 2030, compared with 2017 levels [4]. But unfortunately, according to a latest assessment by the European Environment Agency, this target is unlikely to be met [5].

In numbers, according to statistics, as can be seen in figure 1, at the level of 2017, around 18 million people in the EU countries suffered long-term discomfort from transport noise and over 73 milions in EEA-33, and about 70 million people in EU-28 were estimated to be exposed to harmful levels of road traffic noise in urban areas, compared to 67.5 in 2012 and 52.6 in 2007 [6]. In 2019, the situation was worsening, over 81 milions people in EEA-33 and over 78 milions in EU-28 were exposed to noise levels above 55 dB (the average level during the day, evening and night, Lden) inside urban areas [7]. In 2020 the situation was even worse, being estimated that around 113 million people in the EEA-33 were exposed to road traffic noise levels above 55 dB, and of these, 36 million were exposed to very high noise levels of at least 65 dB [8]. In developing countries, pollution is more severe due to high traffic density and the absence of traffic belts in large cities; it is estimated that daytime noise levels in these countries are around 75-80 dB. However, over the next two years, the situation improved, so that in 2022 approximately the same numbers were reported as in 2017.

In view of these figures, the targets for 2030 have been revised by the EEA, taking into account two scenarios, according to which the number of people highly annoyed by road traffic noise is

projected to remain approximately the same under the conservative scenario or decrease by up to 20% under the optimistic scenario [9].

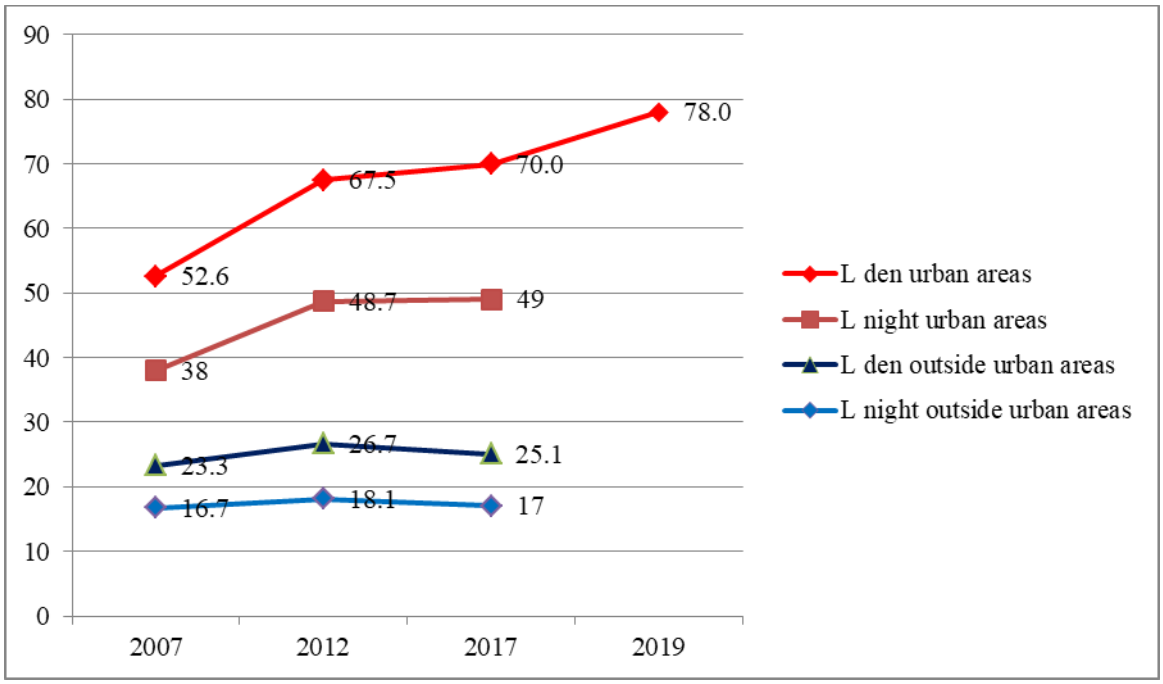

Figure 1. Estimated number of people exposed to unhealthy noise levels, from road transport, based on END thresholds,in the EU-28 in 2007, 2012 and 2017 (2019), in millions [6].

Examples of measures foreseen by the European Environment Agency as necessary to achieve the new 2030 targets include electrification of 50% of the road vehicle fleet in the optimistic scenario and electrification of 25% of the road vehicle fleet in the less ambitious scenario, but in line with the current EU regulation on vehicle noise. In recent years, the number of newly registered electric cars has increased significantly, with more than 876000 battery electric vehicles (BEVs) and 852000 plug-in hybrid electric vehicles (PHEVs) newly registered in the EU-27 in 2021, representing in total 17.8% of all newly registered cars, a significant increase of 7% compared to 2020, in 2015 the percentage was only 1.2% [10]. It is preview that the number of EVs will registry an exponential growth in the next period, in the policy options of the European Commission being estimated that by 2040, 140 million BEVs and by 2050, 235 million will have a fully electric or hybrid powertrain [11].

3. Considerations on the impact of automotive noise on passengers and pedestrians

When talking about noise and vibrations of road vehicles, in general, reference is made to those that commonly occur during their operation and, especially, when they create discomfort to the human senses or pollute the environment. However, if the principle of sustainability is taken into account, the noise and vibrations produced during the entire life cycle of motor vehicles, throughout all the constructional and functional stages, which have a negative impact on the environment and the quality of life, particularly in terms of the level of comfort felt by people, should also be added. Moreover, the level of noise experienced influences, together with the vibrations transmitted and the perceived degree of finish, the comfort and quality of the vehicle, and ultimately has an effect even on sales and in-service appreciation [12].

In today's context of the need to ensure better passenger comfort and lower ambient noise levels, especially in big cities, cars need to be as quiet as possible. Thus, car noise and vibration, together with comfort or harshness, constitute an inseparable trio, symbolised by the acronym NVH, representing today an important indicator that characterises the performance of cars and that can,

implicitly, affect positively or negatively the image of a brand, which is why it is taken into account from the design phase. While both noise and vibration are measurable quantities, harshness is a subjective characteristic associated with noise and vibration that refers to the discomfort of hearing unpleasant sounds or feeling unwanted vibrations, with the level of sensitivity differing from person to person [13].

Generally, the main sources of NVH in cars can be divided in three categories: mechanical (brake friction, engine operations, tire contact patch and road surface), electrical (driver alerts, electromagnetically induced acoustic noise and vibration coming from electrical actuators, inverters), as well as aerodynamic (cooling fans, the wind and the sound of airflow along the car's body). Once the source of a particular sound is identified, the most appropriate sound reduction and control techniques are determined and applied, such as: replacing certain materials, adding thicker insulation to the vehicle body, using customized tires for lower noise, modifying interaction flows or installing different sound barriers.

Although electric vehicles are considerably quieter than traditional vehicles with internal combustion engines, the interior noise of an electric vehicle contains significant high-frequency noise components caused by the electric motor, noise from battery and electrical motor cooling systems, heating and air-conditioning units, airstream and wind resistance, creaking sounds, which can be subjectively perceived as annoying and unpleasant. Also, an important source of NVH in the interior of the electric cars is while the tires are rolling on different types of rough surfaces, roads with grooved concrete or uneven pavements. In a comparative study on the NVH performance in the interior passenger compartment, at some constant speeds, similar performance at high frequency for electric and termic vehicles were founded [14].

Faced with these new challenges, and in order to ensure a quiet and comfortable journey for drivers and passengers, car manufacturers and suppliers, as well as specialized firms and passionate people, are looking for new types of sound absorption and noise and vibration damping materials and technologies, as well as innovative tools and testing equipment for it. Some such examples are shown in [15]: sound-absorbing textile materials, new materials obtained through the combination of a porous and ultra-light, high-volume absorber, with an air flow resistance layer, as dense as possible, that achieves a good absorbing of sound; a lightweight acoustic meta-material that uses a combination of a lattice structure and plastic film to control air vibrations; Quiet Aluminum, a lightweight and formable laminate, which consists of two skins of aluminum bonded together with a viscoelastic core, a very thin polymer that is approximately 0.02-millimeter thick, used for example on inverters, for reducing their high-frequency noise issues; advanced sensor technology, and active noise control technology, that can be used to capture and cancel road noises, like Silentium, based on innovative algorithms that adaptively follow the changes in the noise spectrum eliminate up to 90% of a sound; sophisticated tools based on transfer path analysis such as Vehicle Interior Noise Simulation, modular tool to generate customized and unique sounds, with of real-time sound synthesis.

There are in the last years a wide interest and research in order to solve the acoustic issues of EV powertrains, a modern engineering simulation workflow by following, usually, three steps: application of a multi-body dynamics analysis tool, a finite element analysis tool, and an acoustic software, which could be enough complicated and fairly time-consuming, in complex design cases. A review of the main theoretical, computational and experimental research conducted and published in recent years, as well as recent advances in NVH research of battery electric cars is presented in [16]. A methodology for predicting interior motor electromagnetic noise has been developed in [17] by using an electromagnetic finite element solver.

When running at low speeds, below 30 km/h, electric vehicles are very quiet and therefore very dangerous for the blind or visually impaired, for inattentive pedestrians and cyclists or those wearing helmets, the risks of accidents being much higher. It is therefore necessary to have a warning sound, but not just any sound, but a specific, futuristic sound that represents the identity of each vehicle, according to representatives of the major car manufacturers. Under EU legislation, fully electric cars

must emit a warning sound at speeds up to 20 km/h, imposing a number of requirements on the system known as Acoustic Vehicle Alerting System (AVAS).

4. Considerations on the impact of vehicle vibrations on human being

Considering the generally damaging, even destructive, effect of vibrations, as well as their negative impact on humans, measuring, controlling and combating vibrations is of particular interest in industry, and over time this field has undergone a natural evolution, from the oldest techniques, to computerized data acquisition and processing systems [18], to the use of artificial intelligence technologies. Right around this time, Frontiers, an important publisher, under the motto "Where scientists empower society - Creating solutions for healthy lives on a healthy planet", invites authors to publish papers for a manuscript entitled "Applications of Artificial Intelligence in Vibration Engineering and Big Data Analytics" [19].

A comprehensive overview of the requirements for the measurement and analysis of vibration and noise in transportation in the United States, Europe, Australia and Japan was performed in [20] and the results show thet its are different between countries, but the parameters and methods used are common worldwide. The challenges, limitations, and potential solutions of the vibration measurement and analysis techniques, and some case studies of their practical application are presented in [21].

If, until recently, research was concerned with the vibrations transmitted by internal combustion vehicles, with electrically powered vehicles being less addressed [22], now and for a long time to come they will focus mainly on electric ones. An exhaustive review of the latest research works carried out on vibrations in electric and hybrid electric vehicles is presented in [23], alongside by main findings and research gaps identified, and future development needs. Another overview, regarding the sources of vibration in electric vehicle and their identification techniques, from traditional to topical ones, can be found in [24]. In [25] is investigated and proposed an optimal control technique to reduce vibration and noise in switched reluctance motors used in electric vehicle.

In an attempt to find the most accurate and relevant vibration testing tools, comparative experiments carried out under similar operating conditions of running two vehicles, one electric and one combustion, are presented in [26]. The results obtained show, as expected, some measurable differences, in the sense of lower vibration levels for the electric vehicle, but also unexpected similarities for some specific test conditions.

Practical acoustic metamaterials (AMM) based on polymer sheets, that mutually connect spring-mass local resonators, were developed and presented, inside a focus review, in [27], by trying to find innovative solutions for challenging NVH issues.

5. Conclusion

Following the research carried out, even if we cannot yet answer the initial questions, some partial answers can be given on the impact of vehicle noise and vibration on the health and quality of life of people and the environment. Official statistics show, by the sheer size of the numbers, the significant harmful impact of road transport and vehicles noise and vibration on people's health and quality of life, especially in urban areas, during the day.

The significant increase in the number of electric and hybrid vehicles from one year to the next is a reality and a necessity nowadays, and research into the noise and vibration they produce and the comfort they offer is in full swing. This is because electric vehicles are not perfectly quiet and comfortable from this point of view, with research showing the existence of noise and vibration and a state of discomfort induced in occupants under certain operating conditions. New research opportunities, as well as innovations already implemented in production or emerging, require the development of new standards, materials, tools, equipment and test methods in the field of NVH, especially for electric and hybrid vehicles.

As the demand for electric or alternative, non-conventional propulsion vehicles is growing, a sustained effort is needed from all stakeholders to find and implement the most appropriate solutions that meet the needs and requirements of today's consumers on the one hand, but also comply with

existing regulations and standards on environmental protection and sustainable development on the other.

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