1. Introduction

1.1. The relevance of non-exhaust emissions for public policy

Emissions of particulate matter (PM) from motor vehicles originate from two main sources: the combustion of fossil fuel, which is emitted via tailpipe exhaust, and from non-exhaust processes including the degradation of vehicle parts and road surfaces and the resuspension of road dust. The airborne particulate emissions generated by these processes are defined as non-exhaust PM emissions.

Consensus exists in the scientific literature that non-exhaust emissions are an increasingly important source of PM from road traffic and that exposure to PM can have significant adverse effects on human health. A large fraction of the world's population is exposed to levels of fine particulate matter in excess of limit values set for the protection of human health. In Europe, an average of 8.6 months of YPLL (years of potential life lost) are attributed to excessive PM2.5 exposure. Globally, exposure to ambient PM has been ranked as the seventh most important risk factor for mortality, causing an estimated 4.2 million premature deaths in 2015 (Cohen et al., 2017[1]).[1] The welfare costs of premature deaths due to PM exposure amounted to approximately 4.15% of global GDP in 2017 (OECD, 2019[2]).

Despite these demonstrated negative effects, non-exhaust emissions have been only tangentially addressed by public policies to date. Given the magnitude of the social costs they entail and the fact that the transition to electric vehicles will not generate significant reductions in non-exhaust emissions, policymakers should invest resources in determining how best to reduce them via targeted policy instruments.

1.2. The objectives of this report

The report relies on a multidisciplinary review of the current knowledge on non-exhaust emissions as well as on a quantitative analysis that estimates non-exhaust emission factors for three vehicle categories of conventional internal combustion engine vehicles and of battery electric vehicles. The main objectives of the report are the following:

- Describe the sources and processes involved in the generation of non-exhaust emissions;
- Review the main vehicle, road, and driving features determining the magnitude of non-exhaust emissions;
- Review the current knowledge on the health impacts of non-exhaust emissions;
- Estimate the non-exhaust PM emission factors from electric vehicles and compare these factors with those of internal combustion engine vehicles;
- Identify existing technological and policy measures to mitigate non-exhaust emissions;

- Propose a framework for the design of a pricing instrument to address non-exhaust emissions.

Identify next steps regarding research and policy needs to better understand the causes and consequences of non-exhaust emissions and to reduce their external social costs.

Overall, the report urges action in developing a commonly accepted methodology to measure non-exhaust emissions and in carrying out further research to better understand the drivers of non-exhaust emissions and the causal relationships between these emissions and environmental and health effects. Although existing evidence is not mature enough to make specific policy recommendations, the report aims to provide some initial considerations regarding policy instrument mixes that could be used to internalise the social costs of non-exhaust emissions.

1.3. Key findings on the drivers, impacts, and policy responses to non-exhaust emissions

The drivers and impacts of non-exhaust emissions

Non-exhaust emissions are comprised of brake wear, tyre wear, road wear, and road dust resuspension. Brake wear emissions can be influenced by a vehicle's weight, rate of deceleration, the composition of brake discs and pads, rotor temperatures, sliding speed, and contact pressure. Tyre and road wear are also affected by the composition of tyres and road surfaces. Emissions from road dust resuspension depend on a vehicle's speed, size and shape, the porosity and amount of dust on road surfaces, as well as weather conditions. Considerable uncertainty remains regarding the amount of PM that is emitted by non-exhaust sources in real world driving conditions and how this amount varies with changes in the factors identified above.

Exposure to PM emissions is associated with a variety of adverse health impacts in the short and long term, including an increased risk of cardiovascular, respiratory, and developmental conditions, as well as an increased risk of overall mortality. Numerous epidemiological studies have demonstrated, for example, that PM exposure is associated with acute respiratory infections, lung cancer, and chronic respiratory and cardiovascular diseases (de Kok et al., 2006[3]; Heinrich and Slama, 2007[4]), and the effects of PM2.5 are considered to be particularly damaging. The mechanisms underlying the health effects of inhaled PM have been well studied in the laboratory and there is general agreement regarding the key roles played by oxidative stress and inflammation in the physiopathology of the documented health impacts. Research has also found significant correlations between exposure to PM2.5 and fatality rates in previous coronavirus epidemics (Cui et al., 2003[5]; Wu et al., 2020[6])), further increasing the relevance of air quality for public health and the resilience of social systems more generally.

How non-exhaust emissions will develop in future years

Globally, road traffic is responsible for an average of 25% of ambient PM2.5 in urban areas (Karagulian et al., 2015[7]). Although it is difficult to be precise about the overall contribution of non-exhaust emissions to ambient PM, the current body of evidence shows that PM from non-exhaust sources comprise a rising share of PM emissions from road transport (Timmers and Achten, 2016[8]; CEIP, 2019[9]). As the global fleet of vehicles becomes newer and the amount of PM from exhaust emissions continues to fall, the vast majority of PM from road transport is expected to come from non-exhaust emissions in future years (Rexeis and Hausberger, 2009[10]).

In light of the ongoing electrification of passenger road transport, the report provides estimates of the expected changes of non-exhaust emissions due to shifts from internal combustion engine vehicles (ICEVs) to electric ones. To this end, it compares non-exhaust emission factors of new EVs with those of new ICEVs. Assuming lightweight EVs (i.e. with battery packs enabling a driving range of about 100 miles), the report finds that EVs emit an estimated 11-13% less non-exhaust PM2.5 and 18-19% less PM10 than ICEVs. Assuming that EV models are heavier (with battery packs enabling a driving range of 300 miles or higher), however, the report finds that they reduce PM10 by only 4-7% and increase PM2.5 by 3-8% relative to conventional vehicles.

When applied to current vehicle stocks in two sample cities, simulations show that these reductions will lead to very marginal decreases in total PM emissions from road traffic in future years. In scenarios where electric vehicles comprise 4% and 8% of the vehicle stock in 2030, their penetration reduces PM emissions by 0.3%-0.8% relative to current levels. On a global level, non-exhaust PM (PM2.5 and PM10 combined) are expected to rise significantly along with travel demand, increasing by 53.5% in 2030 relative to 2017 assuming an electric vehicle uptake of 4%. A doubling of electric vehicle uptake has a very marginal impact, leading to a growth in non-exhaust emissions of 52.4% by 2030.

Policy responses to non-exhaust emissions

A robust understanding of emission factors, their drivers, and the effectiveness of measures to reduce them will be necessary before being able to comprehensively assess the costs and benefits of various policy options. PM from non-exhaust sources can be mitigated by reducing the amount of PM emitted per vehicle-kilometre travelled (PM emission factor) and by reducing the number of vehicle-kilometres travelled. Given that vehicle travel entails a range of other negative externalities (e.g. congestion and greenhouse gas emissions), reducing the number of vehicle-kilometres travelled, especially in urban areas, should be a key component of policy portfolios to mitigate non-exhaust emissions.

A distance-based charge designed to internalise the social costs of non-exhaust emissions would be effective insofar as it would incentivise both a reduction in vehicle-kilometres travelled as well as a reduction in emission factors. No precedent currently exists for such a charge, in part because non-exhaust emissions have largely been overlooked in policymaking, but also due to the uncertainty surrounding their magnitude and its determinants, and the social costs of their health-related impacts. While a better understanding of the causes and effects of non-exhaust emissions continues to be developed, other measures will be necessary in order to address non-exhaust emissions in the near term.

Vehicle-kilometres travelled in urban areas can be reduced via a variety of policies that either disincentivise the ownership and use of private vehicles or incentivise the use of alternative modes such as public transport, cycling, and walking. Disincentives for private vehicle ownership and use include pecuniary measures, e.g. registration fees, fuel taxes, distance-based charges, and parking pricing, as well as regulatory measures, e.g. urban vehicle access regulations and other types of vehicle bans. Incentives to increase the uptake of alternative modes include improving the coverage, frequency, comfort, information provision, and payment systems of public transit services and improving the quality and coverage of infrastructure for non-motorised modes, such as protected bike lanes, sidewalks, and priority pedestrian crosswalks. In the long term, developing compact urban areas can also contribute to reducing demand for private vehicle use by shortening the distances required to access amenities.

Given the high proportion of non-exhaust emissions generated by tyre wear, priority should be placed on measures that seek to reduce PM emissions from this source in particular, namely vehicle lightweighting and regulations on tyre composition. To the extent that lighter vehicles also emit less PM emissions from brake wear, policies that more explicitly favour vehicle lightweighting can simultaneously address multiple sources of non-exhaust emissions,[2] though potential trade-offs (e.g. regarding safety and other environmental impacts) should be considered. Specific measures to incentivise vehicle lightweighting could include the expansion of weight-based charges. Investing in R&D to develop lighter materials (e.g. high-strength steel and aluminium alloy) will also advance this agenda.

Insofar as population exposure is greatest in urban areas and current congestion pricing schemes are an effective means of reducing motor vehicle traffic in these areas, another policy priority for addressing non-exhaust emissions is the more widespread use of congestion pricing in city centres. These pricing mechanisms could be further optimised to target non-exhaust emissions, for example, by finding ways to differentiate electronic congestion charges by vehicle weight and distance travelled.

Next steps to address non-exhaust emissions

A main finding of this work is that important gaps remain in the current state of knowledge about non-exhaust emissions, specifically with respect to their drivers, impacts, and the effectiveness of mitigation policies designed to address them. Although research on non-exhaust emissions has expanded rapidly in the last decade, more work is needed in this direction. As a result, immediate and continuing policy action should involve investing in research toward these aims.

Given that the development of regulations and policies regarding non-exhaust emissions rely on the use of a standardized measurement methodology, priority should be given to establishing this methodology for each of the processes that generate non-exhaust emissions. Some progress has been made in this regard for brake wear, but similar initiative remains to be taken for the measurement of tyre wear, road wear and road dust resuspension. Developing a commonly accepted methodology for emissions measurement and designing consequent regulations will take time. There is, however, an immediate need to reduce the public health burden associated with non-exhaust emissions in urban areas.

Navigating the report

The report is comprised of three subsequent sections. Section 2 reviews the scientific literature to identify the processes underpinning the generation of non-exhaust emissions including how vehicle, road and driving characteristics determine their magnitude, as well as the consequences of non-exhaust emissions for public health.

Section 3 compares PM10 and PM2.5 emission factors of battery electric vehicles with their internal combustion engine counterparts. Comparisons are carried out via a quantitative analysis that makes use of data from the literature, emission inventories and other sources. Three categories of light-duty vehicles are considered, namely passenger cars, sport utility vehicles and light commercial vehicles.

Section 4 surveys the scientific literature and industry reports to identify currently available technological solutions to reduce non-exhaust PM emissions from wear and road dust resuspension. Furthermore, it reviews policies that have an effect on non-exhaust emissions, even if that is not their primary aim. The report builds on this review by developing a framework for the design of an efficient public policy instrument to address non-exhaust emissions. Finally, Section 4 also provides an overview of the main uncertainties and data gaps on non-exhaust emissions, and proposes next steps for moving forward in better understanding and mitigating PM emissions from non-exhaust sources.

[1] See also http://www.who.int/gho/phe/outdoor_air_pollution/burden/en.

[2] Vehicle lightweighting, moreover, also reduces greenhouse gas emissions (ITF, 2017[11]).

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