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# Estimation of Exhaust and Non-Exhaust Particulate Matter Emissions’ Share from On-Road Vehicles in Addis Ababa City

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***Abstract*—**Vehicular emission is the key source of air pollution in the urban environment. This includes both fine particles ($PM_{2.5}$) and coarse particulate matters ($PM_{10}$). However, particulate matter emissions from road traffic comprise emissions from exhaust tailpipe and emissions due to wear and tear of the vehicle part such as brake, tire and clutch and re-suspension of dust (non-exhaust emission). This study estimates the share of the two sources of pollutant particle emissions from on-roadside vehicles in the Addis Ababa municipality, Ethiopia. To calculate its share, two methods were applied; the exhaust-tailpipe emissions were calculated using the Europeans emission inventory Tier II method and Tier I for the non-exhaust emissions (like vehicle tire wear, brake, and road surface wear). The results show that of the total traffic-related particulate emissions in the city, 63% emitted from vehicle exhaust and the remaining 37% from non-exhaust sources. The annual roads transport exhaust emission shares around 2394 tons of particles from all vehicle categories. However, from the total yearly non-exhaust particulate matter emissions’ contribution, tire and brake wear shared around 65% and 35% emanated by road-surface wear. Furthermore, vehicle tire and brake wear were responsible for annual 584.8 tons of coarse particles ($PM_{10}$) and 314.4 tons of fine particle matter ($PM_{2.5}$) emissions in the city whereas surface wear emissions were responsible for around 313.7 tons of $PM_{10}$ and 169.9 tons of $PM_{2.5}$ pollutant emissions in the city. This suggests that non-exhaust sources might be as significant as exhaust sources and have a considerable contribution to the impact on air quality.

***Keywords*—**Addis Ababa, automotive emission, emission estimation, particulate matters.

## I. Introduction

ROAD transport is the main source that contributes significantly to directly emitted PM in an urban environment. Based on their origin of formation, transport-related particulate matter can be categorized as tailpipe (exhaust) emissions and non-exhaust emission Tailpipe emissions are originated from the combustion of petroleum-based fuels, as a result, harmful chemicals are released into the surrounding air. Non-exhaust sources include vehicle tire and brake wear, road surface wear, corrosion, and re-suspension [1]. Particle matter is classified based on their aerodynamic diameter such as fine, coarse and other species particulate matter. The coarse particulate matter has an aerodynamic diameter of between 2.5 and 10 µm, and a fine particle has an aerodynamic diameter of less than 2.5 µm [2]. Road transport is the biggest mode of transport that has a share of over 95%, including freight and passenger movement in Ethiopia [2].

A numerous study shows that $PM_{2.5}$ is a cause for about 4.2 million deaths and the fifth risk factor among all worldwide death factors, including smoking, diet, and high blood pressure [3]. $PM_{2.5}$ travel hundreds or thousands of miles from its origin and can stay in the atmosphere for long periods. PM contributes a higher share for air quality deterioration in urban areas [4]. PM is a mixture of metals, salts, organic compounds from combustion and elemental carbon [3], [5].

Nowadays, concentration of air pollution is extremely high level; recent studies disclose that 9 of 10 people breathe air containing high levels of pollutants [6]. Also, diseases and deaths are supposed to occur in the majority of Sub-Saharan countries due to indoor air pollution [7]. Children and women are among the most susceptible parts of the population affected, as they spend more time at home where cooking takes place in a very cramped and poorly ventilated environment. They are exposed to toxic pollutants contained in smoke from indoor combustion of biomass fuels [8], [9].

In general, the ambient air quality standard is required to limit vehicular emissions levels. Currently, there is no legally established ambient air quality standard in Ethiopia. Hence, the quality standard has to be determined by law. However, the initiative has to be taken by the Federal Government and Environmental Protection Agency (EPA) to this effect. It has prepared an initial draft ambient air quality standard [9].

Vehicular PM emissions had a substantial effect on outdoor concentrations and traffic [10]. A recent study confirms that people who spend their time near idling vehicles, high crowded traffic roads, and at the bus stop during (loading and unloading) they are highly exposed to the pollution [11]. Therefore, it is vital to assess the contribution and levels of particulate matter from on-road vehicles to the deterioration of the air quality as well as determine the factors that influence the vehicular PM.

### *A. Factors that Contribute to PM Emission from Vehicles*

PM is formed due to incomplete air-fuel mixture and oil in combustion. The amount of oil consumed in combustion and

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its contribution to PM vary greatly from vehicle to vehicle. Even brand new vehicle contributes to PM emission. Besides, a vehicle's service year (age), mileage and emission after-treatment system have an impact on the emission levels [12]. The older throttle body injection (TBI) engines have a lesser fuel atomization efficiency when compared to port fuel injection (PFI) and it emits higher PM than new ones [13]. This indicates that fuel injection systems have a significant effect on PM in gasoline engines; the higher the injection pressure and clean injector condition, the lower the particle emission [14]. The ethanol-fueled injection system engine is less sensitive to the particulate matter than gasoline engines because of its higher volatility and diffusive combustion which produces less soot [14]. The weather conditions and road gradient conditions have their effects on particulate matter. Measurements made in wet highway-road shows reduced concentration of $PM_{2.5}$ which originates from road dust, brake and tire wear and other mechanical sources in addition to tailpipe emissions. It shows higher values during the dry season [15]. Generally, the highest particle concentrations were detected during higher vehicle speed. This leads to rising engine load, exhaust temperature and tailpipe exhaust flow [16]. The transport system has another dimension of emission contributions, around near-roadside PM concentrations, by re-suspending dust present on the road surface [17], [18].

## II. Emission Estimation

### A. IPCC Second Approach Methods

For road transport emission calculation, there are three commonly used ways in the EMEP/EEA approach. The first approach of the EMEP/EEA, Tier I uses fuel as an activity indicator in combination with average fuel-specific emission factors; the second approach, EMEP/EEA Tier II, uses vehicle types, emission standards, and engine sizes in addition to above mentioned parameters [19].

In this study, the EMEP/EEA second approach was used to calculate total road vehicle PM emission. The Tier II method is given in (1):

$$E_{i,j} = \sum_k (N_{j,k} * M_{j,k} * EF_{i,j,k}) \quad (1)$$

E is the estimated emission; $EF_{i,j,k}$ is an emission factor; i represent pollutant type; j represents vehicle categories and k represents vehicle technologies such as emission standards or engine size. $M_{j,k,}$ represent road mileage and $N_{j,k}$ is vehicle number of cars which have j categories and k technologies respectively. The emission factors which were used in this equation are taken from the EMEP/EEA air pollution guide [19].

The emission estimation methodology covers exhaust emissions of $PM_{10}$ and $PM_{2.5}$ contained from the near vehicles. However, all PM mass emission factors are assumed to correspond to $PM_{2.5}$ [20].

### B. IPCC First Approach Methods

Road vehicle emissions produce airborne particles as a result of the interaction between a vehicle's tire and the road surface. Urban driving accounts for higher wear per unit distance due to frequent acceleration and breaking, as a result of cornering and high junctions [21]. Therefore, to estimate the contribution of the tire, brake, and road surface wear, for $PM_{2.5}$ and $PM_{10}$, Tier I methodology was applied. Total traffic-generated emissions for each of the stated codes can be estimated by summing the emissions from individual vehicle categories.

$$TE = \sum_j N_j * M_j * EF_{i,j} \quad (2)$$

where: TE = total emissions of $PM_{10}$ and $PM_{2.5}$ for the defined period and spatial boundary [g], $N_j$ = number of vehicles in category j within the defined spatial boundary, $M_j$ = average mileage driven per vehicle in category j during the defined time [km], $EF_{i,\ j}$ = mass emission factor for pollutant i and vehicle category j [g/km]. The indices are: i = $PM_{10}$, and $PM_{2.5.}$ j = vehicle category (two-wheel vehicle, passenger car, light-duty truck, heavy-duty vehicle).

### C. Study Area

Addis Ababa is the political and economic center of Ethiopia which covers 527 square kilometers area. It is located at 9° 01' 29.89" N and 38° 44' 48.80" E and has 10 sub-cities. The population shortly is expected to grow to exceed 6.5 million residents. Its average elevation is 2,500 meters above sea level, and hence has a fairly favorable climate and moderate weather conditions [22].

### D. Vehicle Population

The total number of vehicle in Ethiopia is estimated at around one million. Among this, 485,120 (48.51%) are registered in Addis Ababa and may a registration code-AA whereas around 50,870 vehicles are registered with the registration code ET on the license plate. Around 25,435 (50%) of ET-code vehicles are assumed as being used in the city. For this study, the total estimated vehicles are around 510,555, which held a share of 51% of the total vehicle population in the country. Vehicles are registered upon their fuel used and engine size as per information provide from City Administration Drivers and Vehicles License and Control Authority as shown in Fig. 1.

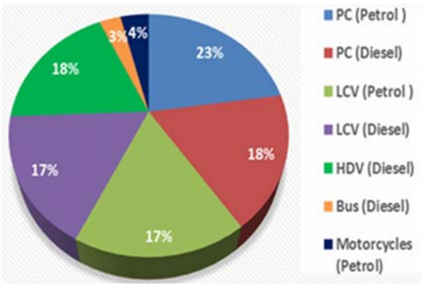


Fig. 1 The population of the vehicle under a different category

*E. Annual Mileage of Each Vehicle Category*

To calculate yearly vehicle emission contribution, annual mileage of vehicles is required. In this study, the annual mileage of each vehicle category was obtained from the baseline study. The annual mileage of passenger cars (PC) and motorcycles is 24,000 km and trucks, Light Commercial Vehicles (LCV), and buses have 50,000 km.

*F. Vehicles Categorized Based on their Engine Size and Technology Used*

Acquiring up-to-date data is very difficult in developing countries. In Ethiopia, vehicles are not registered based on their engine capacity, year of manufacture and emission control technologies. Hence, such information is very important for evaluating the emissions level of road vehicles in the city. To fill the gap, the baseline study was used as input [2]. Based on the baseline data, the population of vehicles under each category is as shown in Fig. 2. This helps to examine the emissions level for technology/emission legislation.

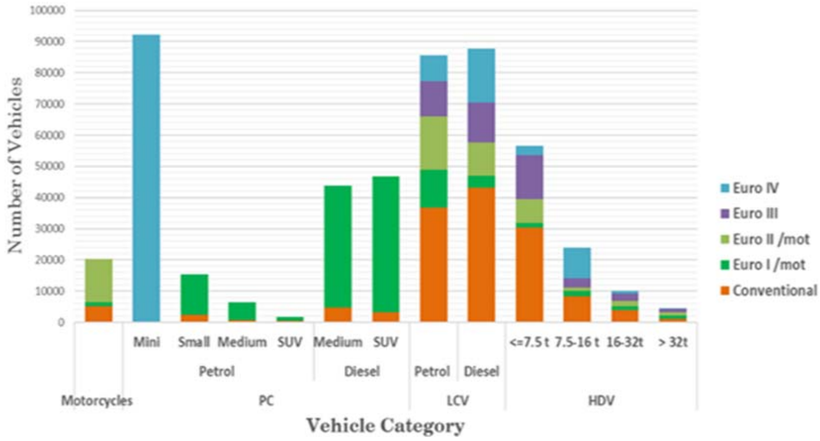


Fig. 2 Vehicle Categorized by engine size, Technology, and type of fuel

In this study, vehicle categories and emissions, controlling technology levels of vehicles are investigated in detail. It seems that 28% of the vehicles in Addis Ababa are conventional engine and 27%, 25%, 11%, and 9% confirm to Euro IV, Euro I, Euro II, and Euro III norms respectively. This data indicate that 72% of the vehicles have an emission control system.

## III. Results and Discussion

The annual road vehicle exhaust emissions, levels of each vehicle's categories' were calculated using EMEP/EEA Tier II methods as stated in (1). The Tier II approach considers the fuel used by different categories of vehicle and their emission norms conformity. However, this method considers all the PM as $PM_{2.5}$. Based on this, emission from each category of vehicle is as shown in Fig. 3.

As shown in Fig. 3, the estimated exhaust PM emission from passenger cars is around 212.86 tons/year. From this, 3.69 tons/year is emitted by petrol vehicles and 209.17 tons/year is by diesel vehicles.

The total estimated exhaust emissions from LCVs are 946.81 tons/year. Among this, 8.67 tons/year is emitted by petrol vehicles and 938.14 tons/year by diesel vehicles.

Busses are a dominant transportation service in the city than any other transport means, particularly for employees, students, and common people because it covers a larger distance at a low price. This increased the daily trip of buses higher and higher through time. The total annual estimated that exhaust emissions by the buses are 274.15 tons. From this share, conventional buses are contributing to 62.9%.

Almost all of the motorcycles registered in the city have a 4-stroke engine. Most of them are brand new and consume less fuel than the previous version. A motorcycle is also used as an optional taxi service in the city. This contributes to a higher mileage covered by motorcycles. Annually, motorcycles release 3.32 tons of PM exhaust emissions to the environment. However, from this portion, a conventional engine shared 51.2% of the total emissions and the remaining were contributed by Euro I, and Euro II families.

In a non-coastal country, freight vehicles are the only option to import and export goods. Likewise, in Ethiopia, the contribution of this sector is undeniably vital. Besides, Addis Ababa is a center of industry and market; therefore, heavy vehicles move all across the city. The total estimated annual exhaust emissions emitted by heavy-duty vehicles (HDVs) are 956.85 tons. From this, 579.62 tons are emitted by a vehicle with a gross weight less or equal to 7.5 tons while 183.9, 129.19, and 64.13 tons are released by vehicles with a gross weight between 7.5-16, 16-32, and greater than 32 tons vehicles respectively.

Non-exhaust road-side emissions are emitted from different sources. The main sources are; tire wear, brake wear, road surface wear, corrosion, and re-suspension. However, in this study tire, brake and road surface wear are dealt with. The assessment only considering $PM_{2.5}$ and $PM_{10}$ particle mass concentrations and vehicles are categorized as two-wheelers, passenger cars, small or large family cars, light-duty trucks (including vans for the carriage of people and goods) and HDVs (including trucks, urban buses). The total annual non-exhaust emissions, emitted by all fleet size are shown in Fig. 4.

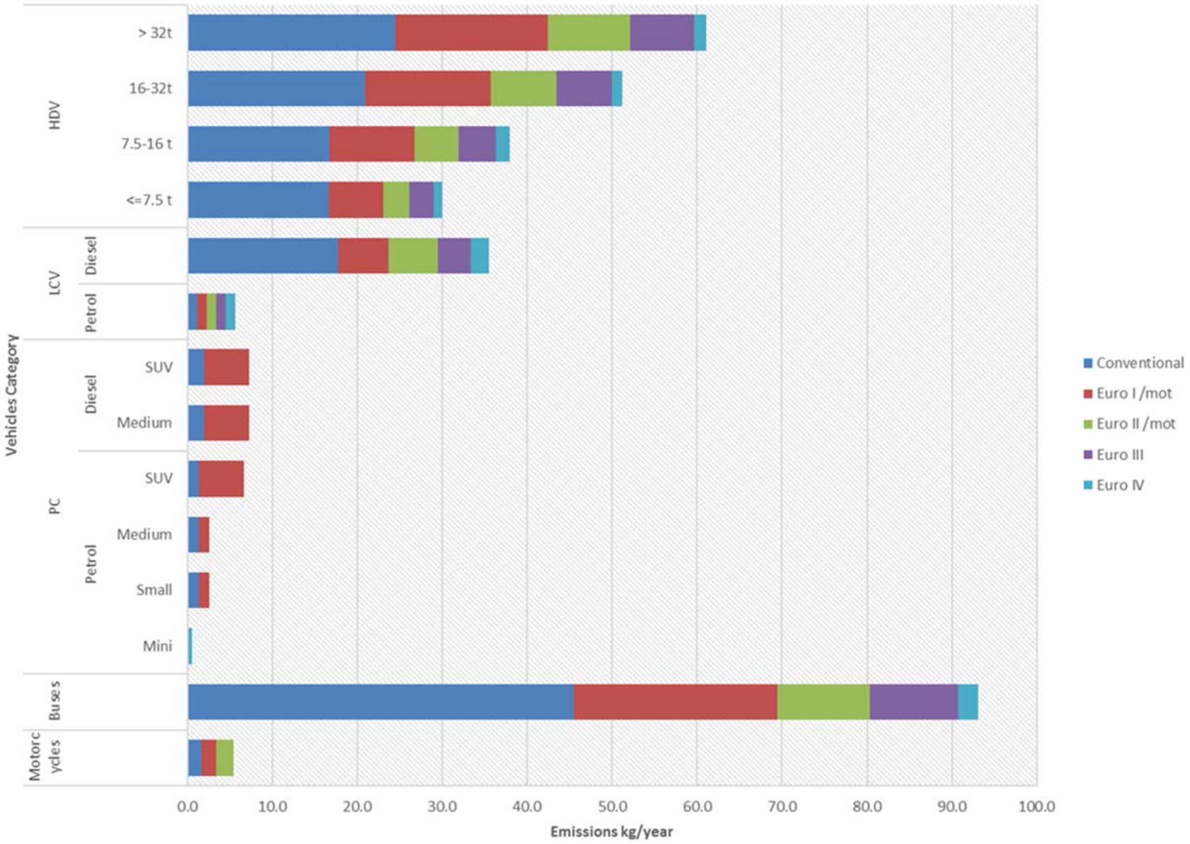


Fig. 3 Annual PM Exhaust emissions from a single vehicle concerning technology level

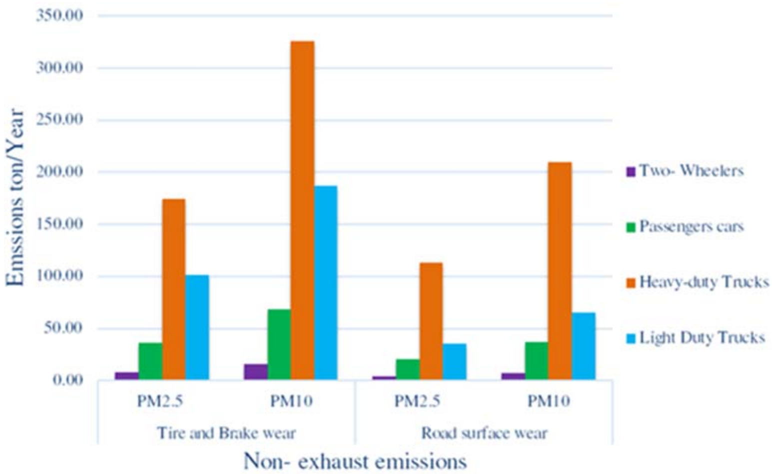


Fig. 4 Total Non-Exhaust PM Emissions from all vehicle categories

The non-exhaust emissions from the tire, brake, and road surface wear may be influenced by their working conditions, designed and material used. The emission contribution of each vehicle category was calculated based on the annual mileage of the vehicles multiplied by the corresponding value of emission factors of the vehicle technology. As shown in Fig. 4 both $PM_{2.5}$ and $PM_{10}$ tire and brake wear non-exhaust emission particles are jointly calculated. The result indicates that brake and tire wear were responsible for 314.4 tons/year of $PM_{2.5}$ emissions in the city. Heavy vehicles (including buses), light-duty trucks, passenger cars, and two-wheelers released around 174.7 tons/year, 101.4, 36.7, and 1.6 tons/year to the environment respectively. Though $PM_{10}$ emissions from tire and brake wear total to around 584.8 tons/year in the city, the share of vehicles varies depending on vehicle type. Heavy vehicles (including buses), light-duty trucks, passenger cars, and two-wheelers released around 326.2, 187.1, 68.4, and 3.1 tons/year emissions respectively.

The variation in road surface wear depends on the road condition, the type of vehicle traveling on it, their speed and acceleration and the weather condition. Road surface wear increases with the moisture level and is 2 to 6 times larger for a wet road than for a dry one. Vehicle speed, tire pressure, and air temperature also affect road wear. As the temperature decreases the tires become less elastic, with the result that the road surface wear rates increase [23]. As shown in Fig. 4, road surface wear contributed around 169.9 tons/year of $PM_{2.5}$ emissions to the city. From this, heavy vehicles shared 67% of the total concentrations. Heavy-duty, light-duty trucks, passenger cars, and two-wheelers emitted around 113.3, 35.5, 20.3, and 0.8 tons/year emissions respectively.

The annual calculated value for $PM_{10}$ emissions from road surface wear contributed to 313.7 tons of emissions to the city. Nevertheless, the share of each vehicle category is 210.1, 65, 37.2, and 1.5 tons/year from heavy-duty, light-duty trucks, passenger cars, and two-wheelers shared respectively.

## IV. Conclusions

From the total cumulative traffic-related particulate emissions in the city, the calculated result show that 63% were emitted from the exhaust tailpipe and the rest 37% were released from non-exhaust emissions sources. However, the contribution of each vehicle category as follows 40% HDV, 39.5% LCV, 11.5% buses, 8.9% PC, and 0.1% motorcycles, respectively. This result indicates that the weight of the vehicles, the number of vehicles in the categories and emission controlling system levels and conditions are the main factors for the share [24].

From the total non-exhaust PM emissions shared in the city, 65% were emitted from tire and brake wear and the remaining 35% were contributed from road surface wear. Furthermore, vehicle tire and brake wear were responsible for an annual 584.8 tons of coarse particles ($PM_{10}$) and 314.4 tons of fine particle matter ($PM_{2.5}$) emissions in the Addis Ababa city whereas, surface wear emissions were responsible for around 313.7 tons of $PM_{10}$ and 169.9 tons of $PM_{2.5}$. This suggests that non-exhaust sources might be as significant as exhaust sources and have a considerable contribution to the impact on air quality. Research output indicates that emission factors for PM from brake wear are significantly larger from HDVs than from LDVs [23].

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