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Effect of Fuel Quality, Vehicle Maintenance and Advanced Emission Control Technology on Pakistan In -Use Light Vehicle Emissions

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Abstract. Pakistan is suffering from some of the worst air quality in Asia. The transportation sector is a major contributor to air pollution along diesel powered vehicles and rickshaws being the primary pollutions source. However, the contribution from light duty vehicles cannot be ignored. In this paper, results from an in-use emission study of over 500 light duty vehicles are reported and discussed. A random geographically diversified survey is conducted to collect data regarding the emissions from in-use vehicles in Pakistan. A review of the government fuel quality policy is provided. Through this analysis, the effects of polices addressing vehicle maintenance and repair, advanced vehicle emission technology and fuel quality are evaluated. These results provide insight to guide further measures to ensure meaningful impact on urban air quality in Pakistan. The same study may also be conducted in other regional countries to support effective emission control policy from the light vehicles.

Keywords. CO emissions; Gasoline Vehicles; Motor Fuel Policy; OBD Preventive Maintenance

1. Introduction

Pakistan is one of South Asia's most urbanized countries and experiences some of the world's worse urban air quality [1-3] The transportation sector is a major source of pollution particularly in urban areas. A recent emission inventory analysis of Punjab, a highly urbanized region including Lahore, considered contributions from power, industry, transport, and crop residue burning and showed that the major portion of total air pollutant emissions are coming from the transport sector [4]. Within the transportation sector, the primary

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contributors to air pollution are the diesel vehicles along with rickshaws and scooters [5, 7]. Numerous studies have focused on adopting more stringent emission control and fuel standards. These approaches have proved very impactful as steps for meaningful reduction in the vehicle's contribution to urban air pollution [8].

Although light duty vehicles are not the primary contributor to air pollution within the transportation sectors, a better understanding of their contribution is important in developing effective policy and regulations to improve urban air quality. The light duty vehicle population in Pakistan is growing. According to the statistical data of vehicle manufacturing in Pakistan, approximately 2.8 million locally manufactured cars has been sold since 1995 [9].Similarly, around 1.9 million of cars has been imported since 1995 [10].

A series of regulatory requirements have been imposed on both the light duty vehicle emission and fuel quality to reduce their impact on urban air quality. In 1993, Pakistan Environmental Protection Agency (EPA) issued in-use standard for three emission parameters, smoke, carbon monoxide and noise. The standards were for both new and in-use vehicles [11]. In 2009, these standards were revised for new vehicles and limits of Euro II were adopted and the in-use limits for vehicles was retained [12].

Pakistan's current petrol specs support the use of high-quality petrol within the market. Figure 1 provides these specs as developed over time starting in 1971 with the adoption of the Pakistan Petroleum Refining, Blending and Marketing rules. In 1985 three types of gasoline mainly based on the RON (80, 87 & 97) were regularized. Lead based octane boosters were not banned at that time but their maximum limit of 0.35 g/l Pb was defined with the high lead grade being removed from the market. Sulphur contents limit was set to maximum of 0.2 wt. %. Lead use gradually decreased with complete prohibition of leaded petrol in 2011 [13]. Sulphur levels were reduced to a maximum of 0.05 wt%. In 2016 the petrol RON requirements were standardized at 92 and 95/97 and in 2019 the use of the manganese based octane booster, mmt, was standardized in all grades at 0.024 g Mn/liter. Inset curves in Figure 1 represents the regularized distillation curves of the gasoline being used in the market.

Building on these actions, there has been significant on-going action in Pakistan to improve light duty vehicle emissions and fuel. Prioritizing these efforts to address the most critical aspects of light duty emissions can bring meaningful benefits. To help identify additional action that can have an imperative impact on air quality, it is important to understand how the light duty vehicles are operating in the real world and identify primary contributors to air pollutions. To our knowledge, there is little information available to assess the in – use light duty vehicle emission in Pakistan.

This paper reports on an investigation to assess Pakistan's in- use light duty vehicle emission performance and the role of vehicle maintenance or repair, the adoption of advanced emission control systems such as catalysts and the fuel quality. The results provide a basis to compare and discuss the current state of light duty vehicle parc and actions taken in other regions around the globe to address light duty vehicle emissions. From this analysis, insight and suggestions for effective next steps in emission reduction for Pakistan's urban centers may be developed.

2. Material and Methods

The objective of this work is to assess the in-use emissions performance of light duty vehicles in the Pakistan car parc. It was desirable to evaluate vehicles across age, mileage and emission technology. Vehicles were randomly chosen for testing and the final distribution was tested against Pakistan vehicle manufacturing numbers over the sampling period as measure of randomness.

Vehicles were recruited randomly for testing in different Pakistan cities including Lahore, Peshawar, Rawalpindi and Islamabad. Data collection was performed from June through December at different workshop and service stations distributed over the respective city. Specific information for each vehicle including make, model, model year, mileage, engine information and information on fuel usage was recorded at the time of testing.

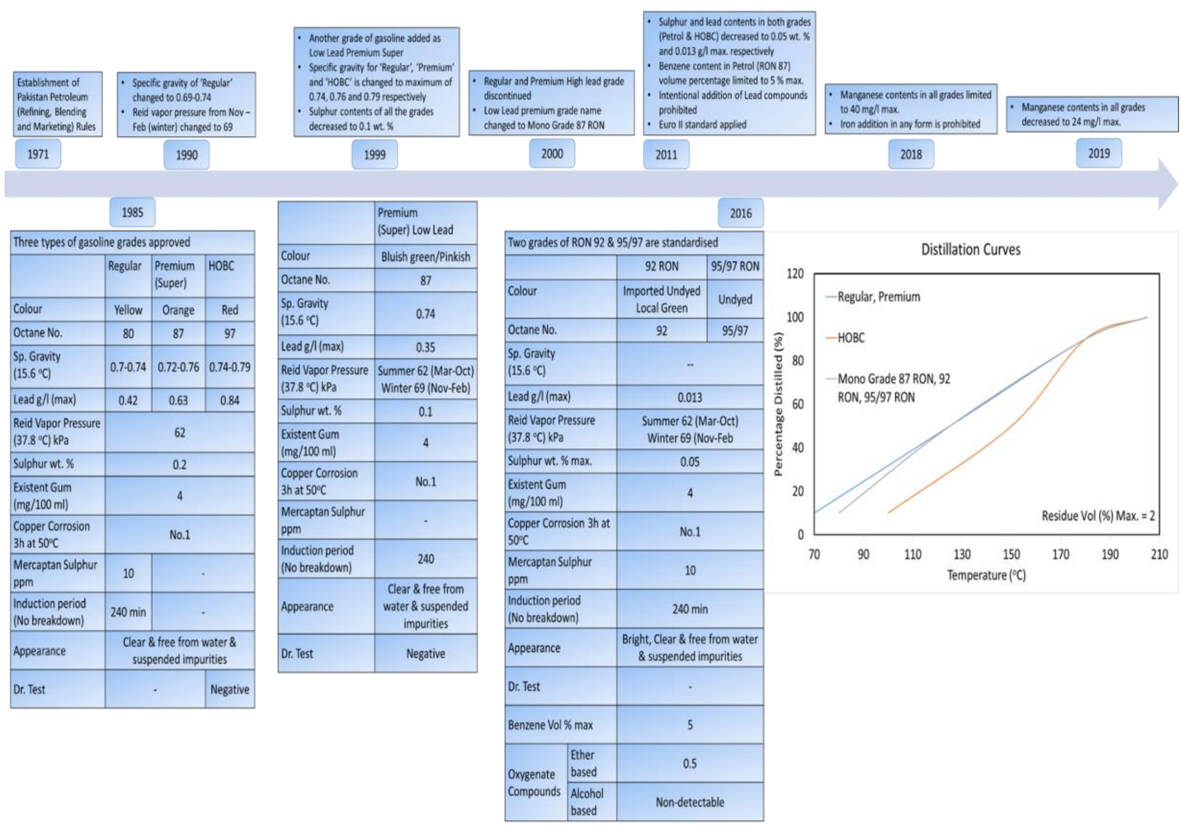

Figure 1: Gasoline policy adopted by Government of Pakistan for commercial sale to vehicles 1971 – 2019, Courtesy Ministry of Energy (Petroleum Division Pakistan), HOBC – High Octane Blending Component

2.1 Vehicle recruitment

2.2 Vehicle Testing

Vehicle CO emissions were measured using an Infrared Industries gas analyzer model no. FGA4000XDS. The analyzer was configured to provide CO measurement and engine speed (rpm). For vehicles equipped with on board diagnostics (OBD), an AUTEL MaxiCOM model no. MK808 scanner was utilized. The scanner has the capability to analyze various automobiles manufactured by different companies.

The vehicle was placed on the ramp in neutral gear with engine switched off. The vehicle was thoroughly checked for leakage in engine oil, gear oil, steering oil, exhaust system/corrosion or dents and catalyst type. The presence of a catalyst was validated by tapping the catalyst housing to check whether catalyst was present or not. After the thorough check, the gas analyzer probe was inserted into the exhaust pipe and tachometer was connected to the engine plug coils wire.

The vehicle was started and kept at idle until RPM and engine temperature stabilized. Once stabilized, the CO reading was recorded, and engine rpm was then increased to approximately 2000 rpm and CO reading was recorded. The OBD scanner was then connected to the standard port if supported by the vehicle. After running an automatic scan, DTC codes were recorded. The CO reading at 2000 rpm and presence of DTC codes were utilized as a check to data. Further, the idling state of engine CO emission may be an indicator of air to throttle ratio malfunctioning and will be analyzed.

3. RESULTS AND DISCUSSION

3.1 Vehicle Population tested

A total of 528 vehicles including vehicles manufactured by Suzuki, Toyota, Honda and other manufacturers were tested for exhaust CO emission. Vehicle model year ranged from 1975 to 2019 with a median age of about 12 years. Minimum and maximum recorded vehicle mileage is 4,900 km and 905,000 km. (Figure 2). Average mileage is around 150,000 km. 10 %, 20 % and 40 % vehicles has less than 50,000 km, 80,000 km and 100,000 km mileage respectively. About 8 % of the tested vehicle had odometer readings of greater than 400,000 km. Across the vehicles sampled, the median annual mileage accumulation was 11844 km/yr and ranged from 786 to 92419 km/yr.

Figure 3 shows the vehicles tested as distributed across the top manufactures for the total number of vehicles assessed and for vehicle assessed that were locally assembled in Pakistan. There are three major companies assembling vehicles in Pakistan namely Suzuki, Toyota and Honda. Since 1995, approximately 2.7 million vehicles were assembled in Pakistan. Suzuki, Toyota and Honda assembled approximately 1.5, 0.7 and 0.26 million vehicles respectively. As per the new Government vehicle policy locally assembled vehicles are expected to increase further [14]. For comparison, the distribution of vehicles locally manufactured since 1995 is included in Figure 3. Comparing the locally manufactured vehicles included in the study versus the makeup of the locally manufactured vehicles since 1995, there is good agreement. This indicates the randomly sampled set used in this study provids a good representation of vehicles in the car parc. Locally manufactured vehicles represent the major part of the in-use vehicles. The inclusion of imported vehicles in the testing, accounts for the differences between the distribution of vehicles tested and that of locally assembled vehicles especially for Toyota and Suzuki vehicles.

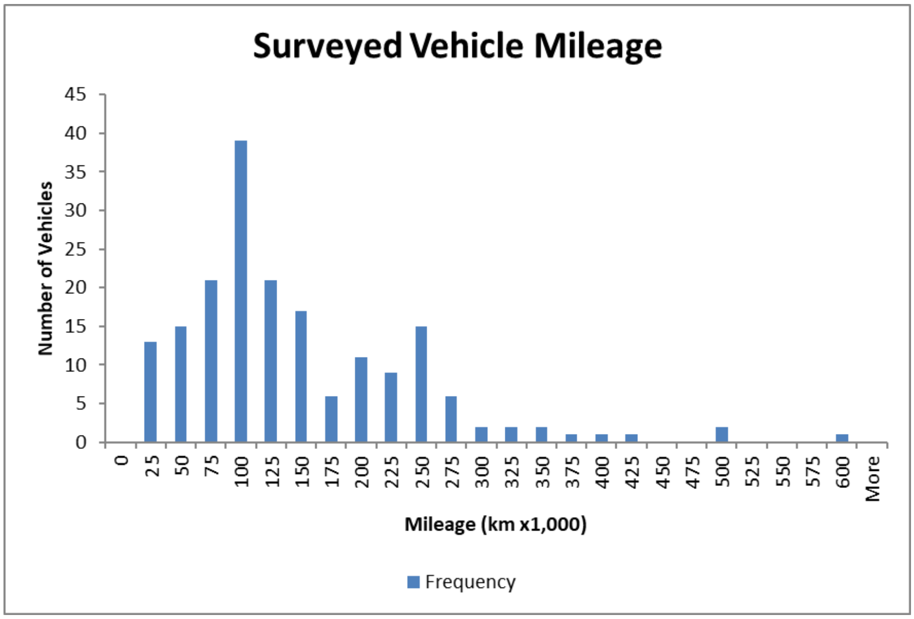

Figure 2 Mileage distribution for tested vehicles.

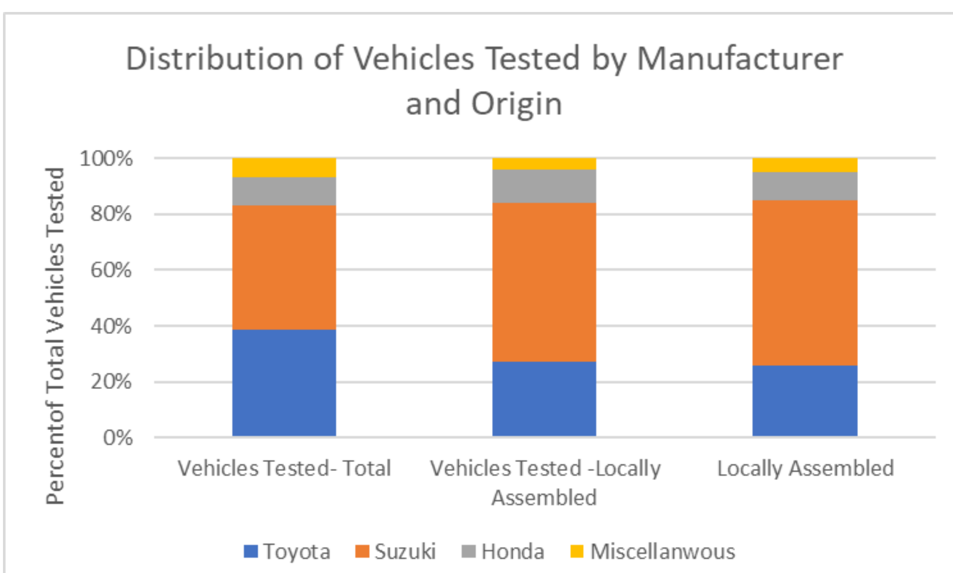

Figure 3 Distribution of total tested vehicles, tested vehicles assembled in Pakistan and the vehicles assembled in Pakistan since 1995 [9]

3.2 Emission Performance

In the following analysis, vehicle CO emission levels are directly compared and assessed against the EPA Pakistan standards (6% CO) for in-use vehicles. For the idle test, the vehicle CO% was found to range from close to zero, to 13.5% with an average emission of 1.1% and median of 0.25%. It was found that about 5% of the vehicles failed to meet EPA Pakistan's in-use standard for CO%. When measured at high speed, average CO emission was 1.14% and ranged from close to zero to 13.6% with a median of 0.4%. The high-speed emission measurement was found to be very similar to those recorded at idle and are not discussed further.

There was a broad range of CO emissions from the vehicles tested. Vehicle emissions increase for several reasons. As the vehicle accumulate mileage, normal deterioration, wear or cleanliness of engine components can result in increased emissions. In addition to the mileage accumulation, vehicle maintenance or repair, the adoption of advanced emission control systems such as catalysts and the fuel quality will impact vehicle emission to different degrees. In this broad-based sampling of the car parc, all these factors are in play and must be considered when evaluating emission performance. In this analysis, each of these three factors are investigated. The size and breadth of this vehicle sampling programs provides potential insight into the impact of these critical factors on vehicle emission performance and effective means to further reduce the emissions.

3.2.1 Vehicle mileage

As the vehicle is used and accumulates mileage, mechanical deterioration of the engine and drivetrain can lead to increased emissions. In addition, emissions from catalyst equipped vehicles increases with mileage as catalytic activity decreases due to accumulated thermal deterioration and poisons/aging [15]. In this study, vehicle with mileage distributed across a broad range were tested Figure 2. In Figure 4, the vehicles with sequentially increasing mileage were grouped in bins of 50 vehicles to compare emission with mileage accumulation. For each bin, the average CO emission of 50 vehicles was calculated and plotted versus the average mileage for vehicles in that bin. The average emissions from the in-use vehicles increased rapidly during the initial 100,00 to 200,000 km and level off at higher mileage. Even using groups of 50 vehicles, we see scatter in the emission versus mileage curve. This scatter is primarily driven by a few outliners vehicles that displayed high CO emissions, often failing the in-use standard. It is recognized that the vehicles emissions are influenced by several factors and in the next sections the impact of repair/maintenance, vehicle emission technology levels and the fuel quality are analyzed and discussed.

3.2.2 Maintenance and Repair

Regular vehicle maintenance and repair are considered important steps in reducing air pollution from vehicles. Studies have demonstrated that a disproportionate amount of the total emission come from the relatively small number of vehicles that require repair [16]. The onboard diagnostic (OBD) system is an emission control technology developed to reduce emission due to maintenance or repair needs. The OBD system monitors the operation of the vehicle and its components and identifies malfunctions or deterioration that can impact operation or emissions. It provides the operator with a warning when maintenance is required. Many of the vehicles in the Pakistan are equipped with onboard diagnostic (OBD) systems.

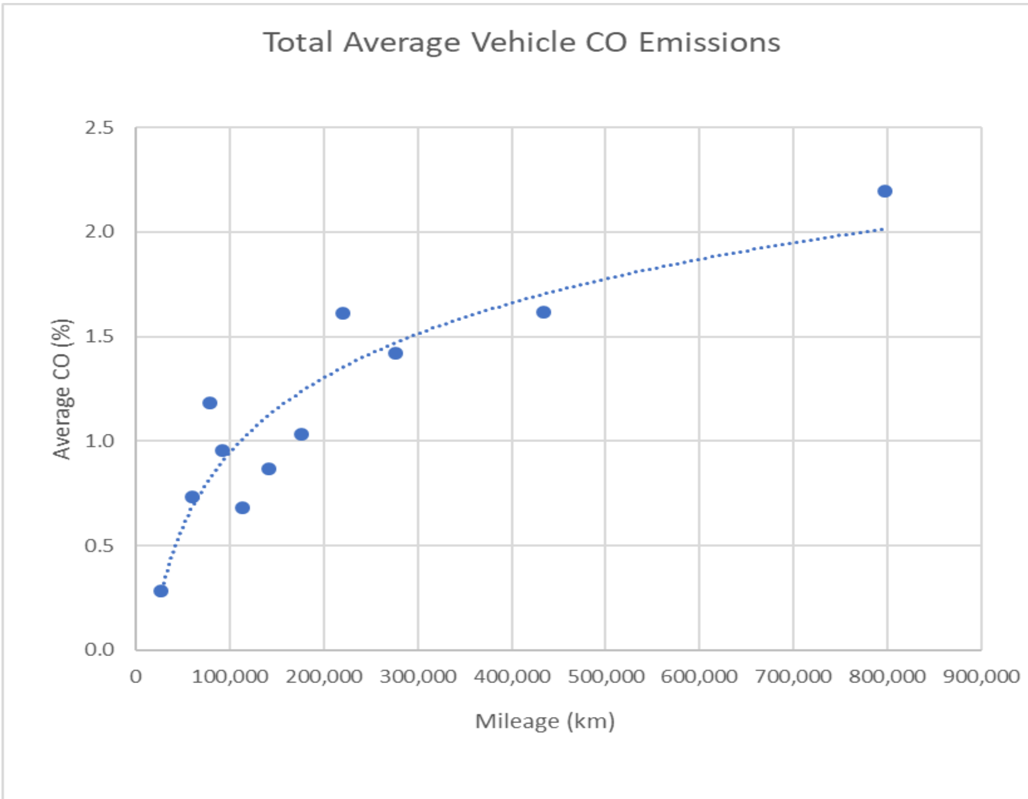

Figure 4: Average CO emission for bins of 50 vehicles with sequentially greater mileage as a function of the average mileage for the vehicles in that bin.

In this assessment of in-use vehicle 296 vehicle are equipped with OBD systems. Compared to around 8% non-OBD vehicles that failed in-use vehicle CO emission criterion only about 2 % of OBD equipped vehicles failed to meet in-use vehicle CO emission criterion. While the OBD equipped vehicles are usually equipped with catalyst and fuel injectors, these findings are consistent with the view that OBD equipped vehicles experience improved maintenance and repair resulting in lower emissions than non-OBD vehicles. While there is evidence that adaption of the OBD system has reduced the number of vehicles failing the emission standard, it is important to consider the small fraction of vehicles that failed the CO standards These vehicles have a disproportionate impact on overall emissions from the vehicle parc. In Figure 5, the cumulative mass emission is presented for vehicles as ranked by CO emission level. The vehicles failing the EPA Pakistan in-use standard represent the top 5% of all vehicles tested based on CO emission levels. These vehicles are responsible for 38% of the total emissions based on the idle CO test. This behavior is consistent with findings in other regions where a small number of high emitting vehicles are responsible for outsized impact on emissions [17]. It should be noted, that these high emitting vehicles have been shown to be responsible for a disproportionate level of emissions that plague urban centers including particulate, air toxics and ozone forming materials [18]. Many policy makers have pursued programs to drive the repair or removal of the gross emitters from the car parc to deliver an immediate and dramatic reduction on the overall vehicle emissions.

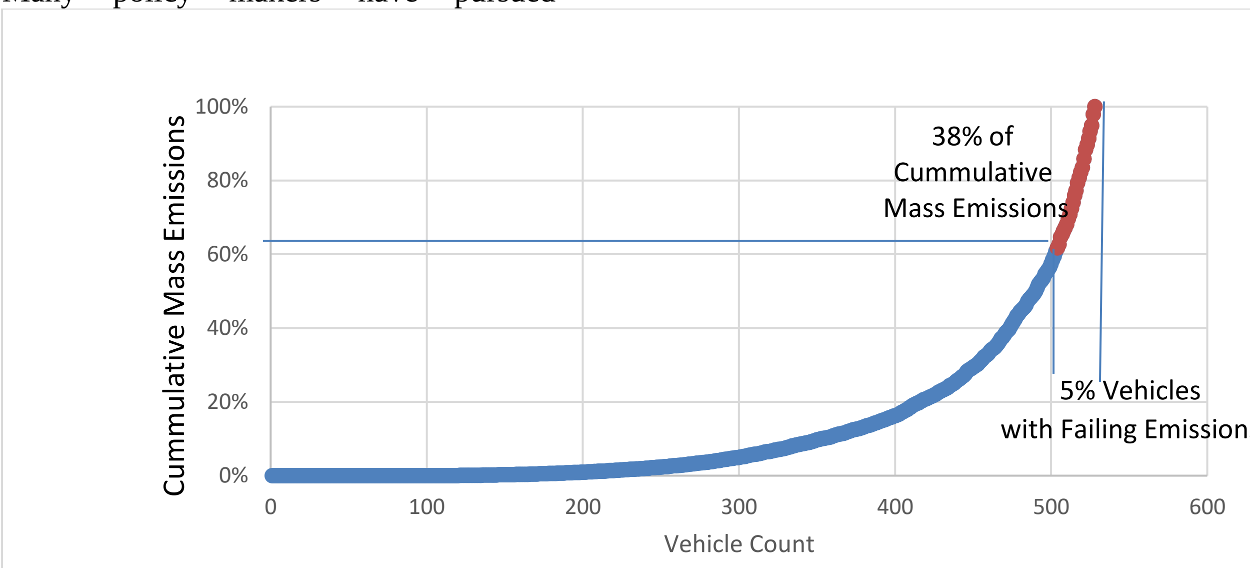

Figure 5: Cumulative mass CO emission ranked by vehicle CO emissions. Vehicles failing the emission test represent about 5% of total vehicles tested.

3.2.3 Advanced Vehicle Emission Control Technology

The exhaust catalyst plays an important role in the reduction of CO emission as well as other emissions. In Pakistan, a considerable number of in-use vehicles are not equipped with catalyst. About 7% of the non-catalytic ones did not meet the EPA CO emission criteria compared to only 3% of vehicles equipped with a catalyst

To provide a further understanding of benefits of emission control technology on air quality, it insightful to assess the emission of properly functioning non-catalysts equipped vehicles and compare their emission performance to the properly functioning catalyst equipped vehicles. As discussed in the previous section, the Pakistan emission regulations identifies vehicles whose emission systems are operating properly as those that pass the in-use emission standards vehicles. This represents about 95% of the vehicles tested in this study. The durability of the emission system also has a significant impact on a vehicles total emission over the vehicle life. To ensure vehicles are designed and manufactured to deliver long term benefits of an efficient emission system, vehicle emission regulations evolved to set a limit on the emission system deterioration. A vehicle not only must meet emission requirements when new but also over a defined useful life. The useful life represents the age, whether in km or years, over which the emission system is designed to operate. The system is then engineered to account for the normal deterioration experienced in-use and provide acceptable performance. The Euro II emission regulation to which Pakistan vehicle must comply, impose a new vehicle emission requirement but do not have a defined useful life. The concept of useful life is still important to assess expected performance of an emission system. Vehicles that meet the standards of Euro IV and later are required to meet a useful life of 160,000 km. which will be applied in this work to assess the performance of catalyst emission control technology in-use.

The emissions from properly operating non-catalyst and catalyst equipped vehicles display the expected profiles as vehicle accumulate mileage, Figure 6. For vehicles without catalyst, the emissions measured at the tail pipe are expected to be at similar levels as the exhaust gas exits the engine. The overall levels are determined primarily by efficiency of combustion, and it is influenced by factors like engine air to fuel ratio, fuel mixing, air induction and oil consumption. Because of these factors, individual vehicle emission can vary, but as seen in Figure 6, CO emission across the whole fleet of vehicles change very little as vehicles age.

For catalyst bearing vehicles, these same factors can impact the CO levels coming out of the engine, but the catalyst acts to destroy most exhaust emissions before it exits the tailpipe. As the catalyst ages, it loses efficiency and gradually emissions increase as seen in Figure 6. Even when emission is compared across the stringent useful life requirements for Euro IV vehicles, the catalyst equipped vehicles deliver significantly lower total emissions than observed from the non-catalyst vehicles. Moving beyond the Euro IV useful life, emission system performance continually drops with aging and emissions approach those observed from non-catalyst equipped vehicles. This behavior is observed in Figure 6, as catalyst equipped vehicles reach around 250,000 km to 300,000 km, a point almost twice the useful life expected from Euro IV vehicles emission systems.

In general, catalysts are classified as two types based on their location relative to the engine exhaust manifold, closed couple and underfloor. Close coupled catalysts are general considered to be one of the critical advanced technologies utilized to achieve ever more stringent emission standards [19]. Although the close coupled catalyst is mounted close to the engine and potentially more susceptible to greater thermal aging and poisoning, of the vehicles surpassing the EPA limits, there were almost 1.5 times as many vehicles with underfloor catalyst vs close coupled catalysts. Considering vehicles that are operating properly and pass the in-use test requirements, the vehicles with closed coupled catalyst displayed lower CO emission and lower deterioration rate than the vehicles equipped with underfloor catalysts for in-use vehicles as depicted by Figure 7. The deterioration rate is the rate at which the emission increase as vehicles accumulate mileage and is a measure of the overall rate at which the emission system loses activity. All vehicles were brought to stable operating temperature before emission testing, so one possible explanation is that the inherently lower temperature expected in the underfloor catalyst location resulted in lower activity, magnifying the impact of aging and resulting in higher emission and higher deterioration rates. These findings are also consistent with difference in observed failure rates for the underfloor and close coupled catalyst vehicles.

In addition to assessing the role of exhaust after treatment the results were used to evaluate the role of electronically control and fuel injection. These technologies enable much more precise control of engines air to fuel ratio. This is specifically important for good catalyst performance. As expected most, 99%, of the catalyst equipped vehicles also had fuel injection, while 75% of the non-catalyst vehicles were equipped with carburetor systems. Around 3% vehicles with injection system, failed to meet EPA criteria of CO emission. On the other hand, the percentage of failure for carburetor vehicles was around 7%.

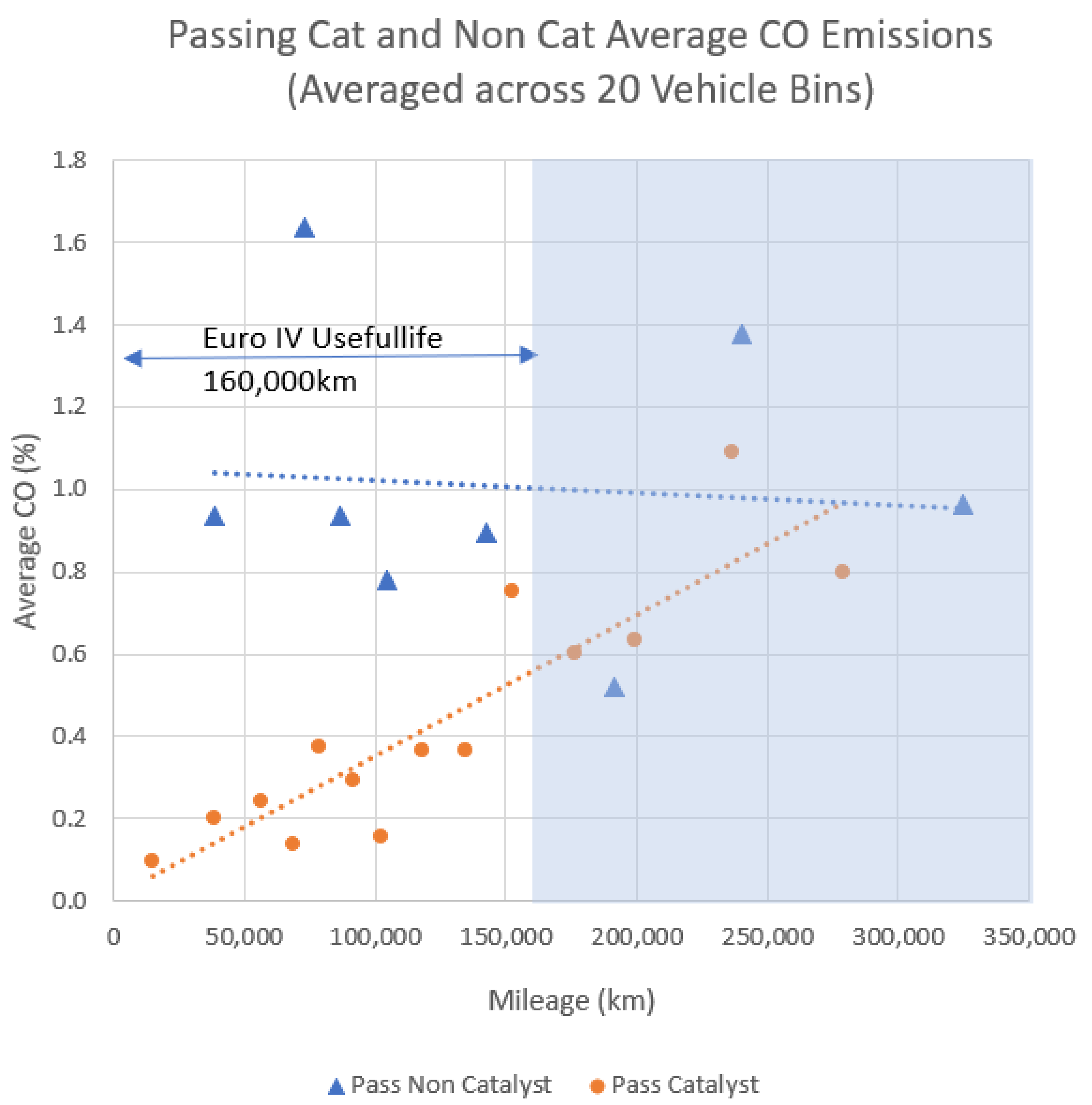

Figure 6: CO emission profiles for catalyst equipped and non-catalyst vehicles. Vehicles sorted by increasing mileage with average emission

and mileage reported bins of 20 vehicles.

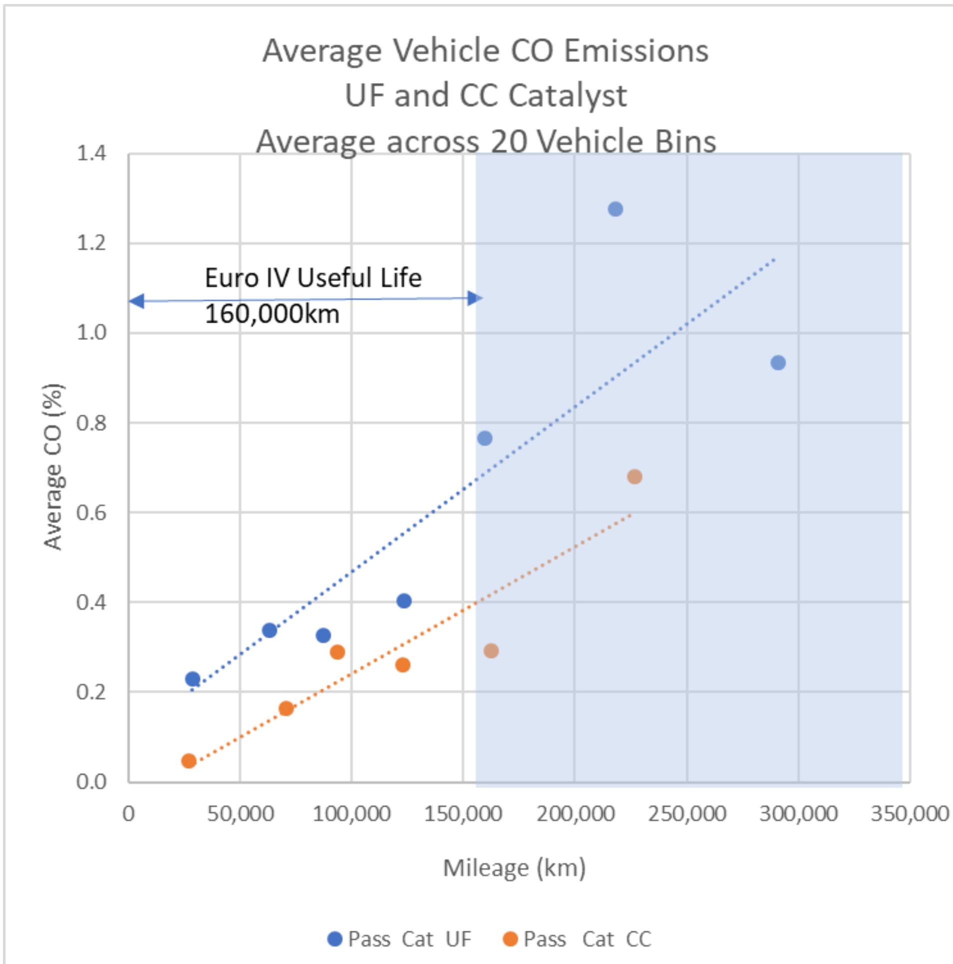

Figure 7: CO emission for closed coupled and underfloor catalyst equipped vehicles. Vehicles sorted by increasing mileage with average emission and mileage reported bins of 20 vehicles.

3.2.4 Fuel Quality

Beginning in 1971, Pakistan has developed and implemented a series of Fuel Quality Regulations of increasing stringency. These regulations are focused on assuring an available petrol pool that meets vehicle performance requirements and lowers vehicle emission though cleaner burning fuels Figure 1.

Under current Pakistan Fuel Quality Regulations, vehicles primarily use either CNG fuel or operate on Regular grade petrol (91/92 RON) or Hi-octane (>95 RON) standardized in 2016. Recently Government has introduced a maximum limit of Mn at 24mg/l for the manganese-based octane boosters for use in the petrol grades. Previously this amount is reported as high as 86 mg/l. Based on owners reports of fuel grade typically used, a comparison of CO emissions gives an overall view of vehicle emission performance Figure 8. There were fewer Hi-Octane fueled vehicles that have accumulated high mileage compared to vehicle utilizing regular petrol or CNG. For this comparison, to minimize the impact of different mileage accumulation, emissions were compared for vehicles with mileage accumulation up to 230,000 km, the maximum mileage for a vehicle using Hi-Octane fuel. For reference, it should be noted this exceeds the 160,000 km useful life requirements under Euro IV. The average mileage for the CNG, Hi-Octane and Regular fuel vehicles was similar at 136,000, 123000, and 125,000 respectively. The vehicles that utilized CNG displayed slightly lower CO emission than the vehicle that utilized Regular petrol while vehicles using Hi-Octane displayed more than 60% reduction in CO emission compared to either the CNG vehicles or vehicle fueled with Regular grade petrol. As the vehicle assessed were of similar mileage, the 60% reduction in CO emissions for the vehicle utilizing Hi-Octane petrol maybe attributed to either the fuel composition, the vehicles emission control system or a combination of the two.

During the assessment of vehicles that failed to meet the EPA criteria of 6% CO emission, it was found that all the catalyst equipped vehicles that failed to meet the standard were older than 2011 model year. The maximum emission of the catalyst equipped vehicles from the 2011 model year or newer was about 2.5% CO. These findings are consistent with the banning of leaded petrol in 2011 and expectation that the pre-2011 vehicles were potentially operated on leaded fuel which is known to poison catalytic activity [20]. This apparent poisoning was not observed for vehicles operating on fuels post 2010 and demonstrates that high RON, unleaded, low sulfur fuel adopted in Pakistan after 2010 and currently in the market is enabling effective emission system performance.

To further explore the role of fuel quality, it is informative to consider the petrol fuel vehicles and the performance of the vehicles that were exposed to the different petrol grades during their lifetimes. The addition of lead was prohibited in 2011. Comparing emissions vs mileage accumulation for pre 2011 model year catalyst vehicles versus the 2011 and later model year catalyst vehicles Figure 9 the benefit of lead removal is evident. The vehicles operating on the unleaded low sulphur petrol introduced in 2011 had lower overall emissions and a deterioration rate only about half of that displayed by the vehicles potentially exposed to leaded fuel. The vehicles that potentially operated on leaded fuel, as a group demonstrated rapid emission deterioration and within 150,000 to 200,000 km displayed similar CO emissions to those vehicles without catalyst. This suggests the use leaded fuel had poisoned and deactivated the catalysts. It is evident from the data that with the dramatic improvement in petrol quality since 2011, vehicle emission system durability has greatly improved with subsequent reduced CO emission. The current petrol quality has enabled good performance of vehicle emission systems for periods greatly exceeding the Euro IV useful life of 160,000 km.

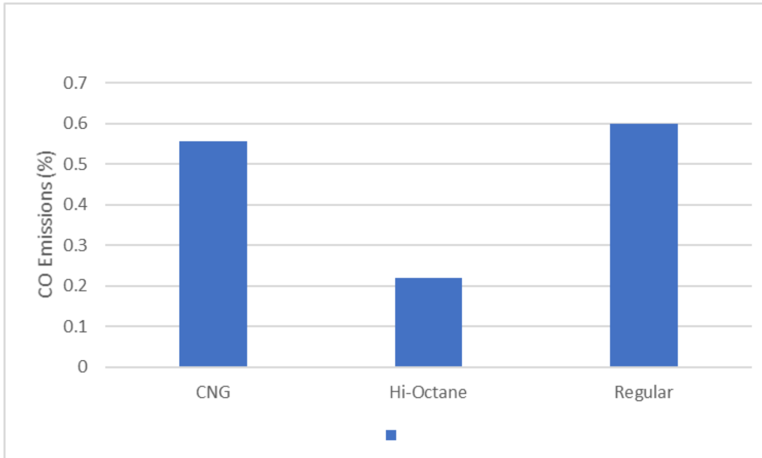

Figure 8: Average CO emission for properly operating vehicles of less than 230,000 km using different fuels.

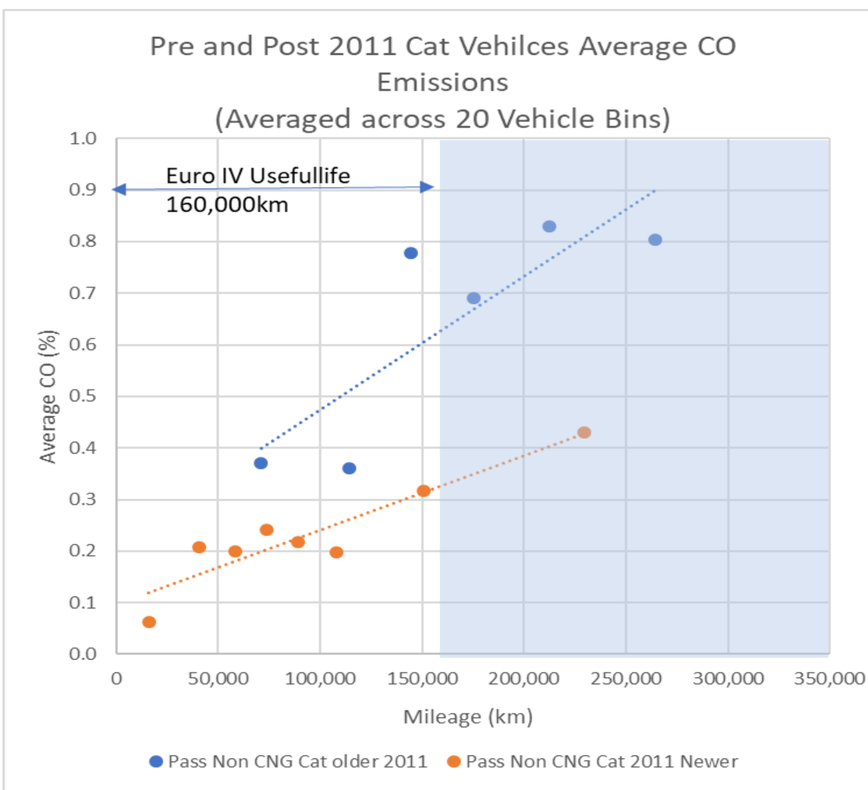

Figure 9: CO emission for pre 2011 and 2011 and newer model year Petrol fuel vehicles. Vehicles sorted by increasing mileage with average emission and mileage reported bins of 20 vehicles.

Conclusions

Pakistan is challenged with significant air quality issues especially around the urban centers. While diesel powered vehicles and scooters are the primary mobile source contributors to poor urban air quality, contributions form light duty petrol and CNG vehicles should also be assessed as meaningful reductions in overall emission and could play an important part in addressing these pressing air quality challenges. For this reason, it is important to identify areas that would provide meaningful real-world reductions. Under real world driving conditions, as the vehicle accumulate mileage, normal deterioration, wear or cleanliness of engine components can result in increased emissions. In addition to the mileage accumulation, vehicle maintenance or repair, the adoption of advanced emission control systems such as catalysts and the fuel quality will impact vehicle emission to different degrees.

Pakistan has made significant strides implementing in-use emission standards, new vehicle emission standards and a series of clean fuel regulations to enable vehicle emission control and diagnostic system to operate effectively. In this work, the monitoring of in-use emissions from a large sample of representative Pakistan light duty vehicles provides insight into the key issues to address to further reduce the adverse effect of light duty vehicle emissions on air quality. It was found that the maintenance or proper operation of vehicles had the single largest impact on emissions, followed by the adoption of vehicle hardware or emission control systems and then fuel quality. Specifically,

<u>Vehicle Maintenance and repair</u>

- Addressing the small fraction of vehicles with disproportionally high emissions is perhaps the most impactful step towards improving air quality. About 5% of the vehicles account for 36% of the emissions based on the CO idle test.
- The adoption of the OBD systems provides a ready means for owners to identify emission system deterioration and render repair. It was found that the non-OBD equipped vehicles failed the emission standard at four times the rate as OBD equipped vehicles.
- The removal of these high emission vehicles provides air quality benefits far beyond reducing CO emissions. These high emitting vehicles are also found to be responsible for a disproportionate amount of other Urban air pollutants such as particulate matter or ozone forming emissions and many policy bodies have adopted removal of these vehicles as cost effective approach with immediate, far reaching impact on air quality.
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<u>Advanced Vehicle Emission Control Technology</u>

- Vehicles equipped with advanced emission control technologies including exhaust catalyst technologies and OBD, demonstrated dramatically lower emission than non-catalyst vehicle even after almost twice the useful life expected for Euro IV vehicles. Compared to noncatalytic vehicles, over the Euro IV useful life, catalyst equipped vehicle delivered a 49.6% reduction in total emissions.
- For vehicles exposed to real world operation, the vehicles equipped with close coupled catalyst, technology employed in advanced emission control systems, delivered better performance than vehicles equipped with underfloor catalysts. The close coupled catalyst displayed average emissions of 0.41% and better durability, with performance

deteriorating at about a 25% lower rate than the underfloor catalyst.

- Adoption of Euro III or later emission standards will drive lower emission from new vehicles but will require years to meaningfully reduce the already small adverse impact of light duty vehicles on Pakistan air quality. After adoption of the Euro III standard there is very little change in exhaust emissions moving through Euro IV, Euro V or Euro VI [21], [22] and at normal vehicle turnover rates, it takes years for these vehicles to become a significant fraction of the light duty vehicle parc. In other regions faced with similar issues, regulators have adopted policies to encourage the more rapid turnover [23].

Fuel Quality

- The Pakistan government has successfully implemented fuel quality regulations to enable effective adoption of advanced vehicle emission control systems. No vehicles equipped with advanced emission control systems introduced after the removal of leaded petrol failed the in-use emissions standard and these catalyst equipped vehicles displayed significantly improve performance and durability compared to catalyst equipped vehicles that potentially used leaded petrol.
- Pakistan petrol pool supports the use of the advanced emission control technology with high octane petrol. Vehicles that utilized the Hi-octane petrol grade displayed more than 60% reduction in CO emission compared to either the CNG vehicles or vehicle fueled with regular grade petrol.
- The fuel quality is in place to support a move to next level of vehicle emission standards. Advanced emission control technology such as close coupled catalyst which are reported to be more susceptible to poor fuel quality, demonstrated better performance and durability during long term operation using real world fuels. The Hi-octane petrol in Pakistan enables vehicles to deliver on superior emission performance and the use of proper octane prevents engine damage, reduces emissions, and optimizes fuel consummation or lowers GHG emissions [24].

The results from this study have led to insight into effective means to address light duty vehicle contribution to urban air quality. Encouraging repair or removal of high emitting vehicles, beginning the adoption of more stringent emission control standards and maintaining the high-quality petrol available in the market while protecting the fuel from adulteration are key steps to reduce light duty vehicle emissions. As most of the emission from transport sector are derived from diesel powered vehicles and rickshaws, resources dedicated to addressing the contributions form light duty vehicles could easily be expended without any meaningful benefit. The insights developed I form this work are particularly valuable to inform and shape efforts to address light duty vehicle emission that are properly focused.

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تأثير جودة الوقود وصيانة المركبات والتكنولوجيا المتقدمة للتحكم في الانبعاثات على انبعاثات المركبات الخفيفة المستخدمة في باكستان

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الملخص تعاني باكستان من بعض أسوأ جودة للهواء في آسيا ويعد قطاع النقل مساهماً رئيسياً في تلوث الهواء بما في ذلك المركبات التي تعمل بالديزل وعربات الريكاشة كونها المصدر الرئيسي للتلوث. ومع ذلك ، لا يمكن تجاهل مساهمة المركبات الخفيفة. في هذه البحث تم الاطلاع عن نتائج دراسة الانبعاثات أثناء الاستخدام لأكثر من ٥٠٠ مركبة خفيفة ومناقشتها كما تم إجراء مسح عشوائي متنوع جغرافيًا لجمع البيانات المتعلقة بالانبعاثات من المركبات المستخدمة في باكستان كما تم مراجعة وتقييم لسياسة جودة الوقود الحكومية. ومن خلال هذا التحليل تم تقييم آثار السياسات التي المتعلقة بصيانة المركبات وإصلاحها والتكنولوجيا المتقدمة لانبعاثات المركبات وجودة الوقود، وتوفر هذه النتائج نظرة ثاقبة لتوجيه المزيد من التدابير لضمان التأثير الهادف على جودة الهواء في المناطق الحضرية في باكستان. يمكن إجراء نفس الدراسة أيضًا في بلدان إقليمية أخرى لدعم سياسة التحكم الفعال في الانبعاثات من المركبات الخفيفة.

الكلمات المفتاحية:انبعاثات ثاني أكسيد الكربون; مركبات البنزين; سياسة وقود المحرك، الصيانة الوقائية