Mitigating Vehicular Air Pollution: Lessons From Regulatory Frameworks In Singapore And The United States For Sustainable Practices In Ghana

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Abstract- *This study examines the regulatory frameworks and initiatives implemented in Singapore and the United States to mitigate vehicular air pollution and their applicability to other contexts, particularly in Ghana. Drawing on a comprehensive review of literature and governmental regulations, the study evaluates the effectiveness of measures such as emission standards, vehicle emission schemes, and regulations against idling engines in reducing harmful emissions and improving air quality. The study highlights the significant success achieved in Singapore and the United States through collaborative efforts between government agencies, stakeholders, and the public. Based on these findings, the study offers recommendations for Ghana and other countries facing similar challenges, including the adoption and adaptation of regulatory measures, public awareness campaigns, investments in green technologies, and international collaboration. By implementing these recommendations, Ghana can make substantial progress towards mitigating vehicular air pollution, protecting public health, and advancing environmental sustainability.*

Keywords- Air Pollution, Air Quality Index, Carbon Dioxide, Vehicular Emissions.

I. INTRODUCTION

Vehicular air pollution poses a significant threat to public health and environmental sustainability worldwide. With urbanization and industrialization on the rise, the proliferation of automobiles has led to a surge in emissions of harmful pollutants such as carbon dioxide (CO_2), nitrogen oxides (NO_x), particulate matter (PM), and volatile organic compounds (VOCs)[1]. In response to this growing concern, governments and regulatory bodies across the globe have implemented various policy interventions aimed at curbing vehicular emissions and mitigating their adverse impacts.This study explores the efficacy of vehicular emission schemes and regulatory frameworks adopted in different countries, with a focus on the United States, Singapore, and the potential applicability of such measures in Ghana. By analysing the evolution of policy interventions, emission standards, and their effects on air quality and public health, this study seeks to provide valuable insights into effective strategies for addressing vehicular air pollution in emerging economies like Ghana.

The United States Environmental Protection Agency (EPA) has been at the forefront of implementing stringent regulations under the Clean Air Act, targeting key pollutants emitted by vehicles. Through a combination of emission standards, fuel economy regulations, and state-level initiatives, the United States has made significant strides in reducing vehicular emissions and improving air quality over the past few decades[2]. The experiences of the United States serve as a benchmark for understanding the effectiveness of regulatory frameworks in combating air pollution on a national scale.
Similarly, Singapore has pioneered innovative approaches to tackle vehicular air pollution through the implementation of comprehensive emission schemes. These schemes, which incentivize the adoption of cleaner vehicles while imposing surcharges on high-emission vehicles, have proven effective in reducing pollutant levels and promoting sustainable transportation practices. The evolution of Singapore's emission schemes underscores the importance of continuous policy refinement and adaptation to address emerging environmental challenges[3].

Drawing upon the experiences of these countries, this study aims to assess the feasibility and potential benefits of implementing similar policy interventions in Ghana. With

vehicular air pollution emerging as a pressing issue in Ghanaian cities, there is a critical need for evidence-based policy solutions that can effectively mitigate emissions and safeguard public health. By examining the successes and challenges encountered in the United States and Singapore, this study seeks to inform policymakers and stakeholders in Ghana about the potential pathways towards cleaner and more sustainable transportation systems[4].

Addressing vehicular air pollution requires a multifaceted approach that encompasses regulatory frameworks, technological innovation, and behavioural change. By learning from global best practices and tailoring interventions to local contexts, countries like Ghana can make significant strides towards achieving cleaner air and healthier environments for their citizens. This study aims to contribute to the growing body of literature on air quality management and sustainable development, with implications for policy formulation and implementation in emerging economies.

In Ghana, vehicular air pollution presents a multifaceted challenge driven by factors such as rapid urbanization, an aging vehicle fleet, and inadequate infrastructure. The composition of vehicle emissions includes PM, NO_x, CO_2, and VOCs compounds, all of which pose significant health risks to the population. PM, consisting of fine and coarse particles, can penetrate deep into the respiratory system, leading to respiratory and cardiovascular ailments. NO_x and VOCs compounds contribute to the formation of ground-level ozone and smog, exacerbating respiratory issues and impacting overall air quality[5], [6]. Additionally, CO_2 emissions from vehicles interfere with O_2 transport in the blood, causing symptoms ranging from headaches to more severe health complications. These pollutants are further exacerbated by factors such as traffic congestion, aging vehicle fleets, and the quality of fuel used, all of which contribute to poor air quality in urban centres [7] in Ghana.

To address the challenges of vehicular air pollution in Ghana, a holistic approach is necessary, encompassing policy interventions, technological advancements, and public awareness campaigns. Implementing stringent emission standards for vehicles, promoting the use of cleaner fuels, and investing in public transportation infrastructure are critical steps in reducing emissions from vehicles. Additionally, initiatives aimed at improving vehicle maintenance practices and enhancing urban planning to alleviate traffic congestion can further contribute to mitigating air pollution[8], [9]. Public awareness campaigns about the health impacts of air pollution and the importance of adopting sustainable transportation practices are essential for fostering behaviour change and promoting a culture of environmental stewardship. Collaboration between government entities, private sector stakeholders, and civil society organizations is crucial for implementing effective strategies to address vehicular air pollution and safeguard public health and the environment [10].

This study therefore aims to address a critical research gap by comprehensively characterizing vehicular air pollution in Ghana, evaluating existing policy interventions and technological solutions, and developing evidence-based strategies for mitigation. This research aims to provide a detailed understanding of the composition, sources, and impacts of vehicular emissions across different regions and urban centres in Ghana. Through rigorous evaluation of policy effectiveness and technological feasibility, coupled with stakeholder engagement and public awareness efforts, the study seeks to inform policy-making, guide urban planning, and promote sustainable development by fostering cleaner transportation practices, improving air quality, and safeguarding public health and the environment. The findings and recommendations from this research have broader implications for other developing countries grappling with similar challenges, offering insights and lessons learned that can be adapted and applied to advance scientific knowledge, inform policy discourse, and catalyse action towards achieving cleaner, healthier, and more sustainable transportation systems globally.

II. STUDY AREA AND MATERIALS

2.1 Study area description

The Air Quality Index (AQI) serves as a vital tool in assessing air pollution levels in specific locations, with Accra, the capital of Ghana, notably grappling with significant pollution challenges(Fig. 1). Records reveal several months where pollution levels reached hazardous levels, posing substantial risks to vulnerable segments of the population. Among these vulnerable groups are young children, the elderly, pregnant women, individuals with heightened sensitivity to pollution, and those with pre-existing health conditions or compromised immune systems[11], [12] and also a contributing factor to climate change. In 2020, Accra recorded an annual average $PM_{2.5}$ concentration of 26.9 $\mu g/m^3$, categorizing it within the 'moderate' pollution range, denoted by the colour yellow on the AQI (Table 1). This classification typically corresponds to $PM_{2.5}$ levels ranging from 12.1 to 35.4 $\mu g/m^3$,

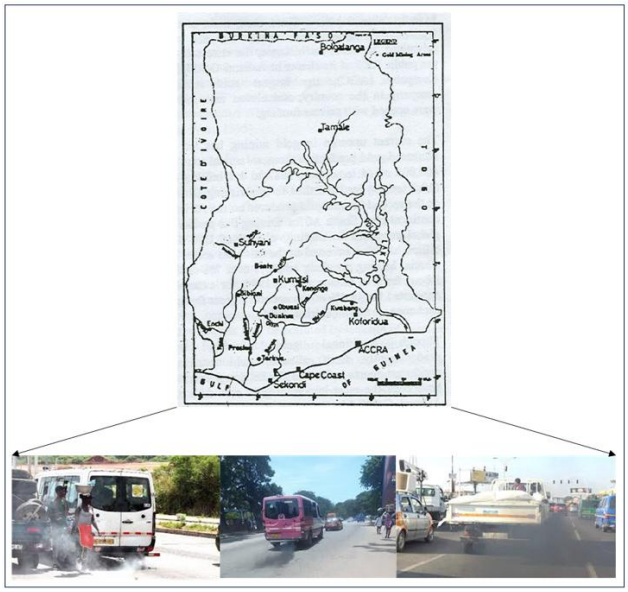

Figure 1: A sample of vehicular air pollution in Ghana. positioning Accra at 492nd place among cities worldwide in terms of air quality ranking [13].

Table 1: Air Quality Index (AQI) Level Classification for Ghana

AQI Value	$PM_{2.5}$ Range($\mu g/m^3$)	Index Color	Pollution Level
0 ─ 50	0.0 ─ 12.0		Good
51 ─ 100	12.1 ─ 35.4		Moderate
101 ─ 150	35.5 ─ 55.4		Unhealthy for Sensitive Groups
151 ─ 200	55.5 ─ 150.4		Unhealthy
201 ─ 300	150.5 ─ 250.4		Very Unhealthy
301 ─ 500	250.5 ─ 500.4		Hazardous

In mid-2021, Accra experienced notably elevated readings of the US Air Quality Index (AQI), another significant metric for gauging air pollution levels. Recording a reading of 89, Accra once again fell within the 'moderate' rating category according to US AQI standards, which typically ranges from 51 to 100. While the US Environmental Protection Agency's guidelines consider any AQI reading between 0 and 150 as acceptable, higher readings within this range may lead to adverse health effects, particularly among vulnerable individuals and the general population. The US AQI is a composite figure derived from key air pollutants, including Particulate Matter (PM_{10} and $PM_{2.5}$), nitrogen dioxide (NO_2), sulphur dioxide (SO_2), and ozone (O_3) [13].

2.2 Understanding and Mitigating Urban Air Pollution: A Focus on Accra, Ghana

Major sources of air pollution in Ghana, particularly concerning $PM_{2.5}$ and PM_{10}, encompass various contributors such as suspended dust from unpaved roads, tailpipe exhaust emissions from aging buses and trucks (Fig. 1), open burning of residential waste, and soot emitted by biomass-fuelled cook stoves [14]. Recently, vehicle emissions have emerged as a growing concern in urban areas, especially cities. While there has been a reduction observed in primary pollutants like sulphur dioxide (SO_2) emissions and concentrations, a more complex regional air pollution problem dominated by fine particulate matter ($PM_{2.5}$) and ground-level ozone (O_3) has surfaced[15].Additionally, black carbon and Volatile Organic Compounds (VOCs) play significant roles in the release of combustion-based pollutants, emanating from sources ranging from cars to factories, and even the open burning of trash. VOCs, such as toluene, styrene, xylene, methylene chloride, and formaldehyde, pose particular risks due to their ability to persist in a gaseous state and contribute to indoor air pollution [4], [16].Black carbon, a primary component of soot, not only poses respiratory hazards but also acts as a climate-changing agent by absorbing solar radiation and converting it into heat, warming surrounding areas where it accumulates. Ground-level ozone (O_3), formed when various oxides of nitrogen (NOx) and other gases are exposed to sunlight, is abundant in Accra and throughout Ghana, presenting health risks such as shortness of breath, lung inflammation, and nausea upon[13]. Although ozone is crucial in the upper atmosphere's Ozone layer, its presence at ground level, often seen as smog, is hazardous to human health. Additionally, pollutants like mercury, lead, cadmium, polycyclic aromatic hydrocarbons, dioxins, and furans contribute to the air quality challenges in Accra, varying in concentration based on industrial and anthropogenic activities occurring in different locations [14].

2.3 Mitigating Air Pollution Challenges in Accra, Ghana: Periodic Concentrations, Health Risks, and Remedial Strategies

Examining the periodic pollution concentrations in Accra, Ghana reveals significant fluctuations in $PM_{2.5}$ levels throughout 2020.The highest readings were observed in January and February, indicating periods of heightened air pollution, likely attributed to various anthropogenic activities prevalent during these months[16]. These activities may include increased vehicular traffic, particularly older vehicles emitting higher levels of pollutants, as well as the burning of waste and biomass for cooking and heating purposes, common practices in many urban areas. Conversely, the lowest $PM_{2.5}$ readings were recorded in April, May, September, and

October, suggesting potential improvements in air quality during these periods. However, the fluctuations underscore the dynamic nature of air pollution in the region, influenced by seasonal variations, weather patterns, and human activities[10], [16].Despite efforts to address air quality issues, Ghana continues to face severe air pollution challenges. According to the IQ-Air Air-Visual's 2019 World Air Quality Report, Ghana ranks among the countries with the highest pollution levels in Africa[17]. The detrimental effects of air pollution on public health are well-documented, with significant associations found between exposure to polluted air and various adverse health outcomes, including cardiovascular and respiratory diseases[18]. Moreover, air pollution imposes substantial economic costs on society, including healthcare expenditures, lost productivity, and environmental degradation. Urgent and comprehensive measures are therefore needed to mitigate air pollution in Ghana, encompassing policy interventions, technological advancements, and public awareness campaigns aimed at promoting sustainable practices and safeguarding public health and the environment[19].

2.4 Legislative Strategies for Addressing Air Pollution: Lessons and Challenges for Ghana

Air pollution, primarily from vehicular transport, poses the most significant environmental threat to public health globally. Recently, the World Health Organization (WHO) issued stricter recommendations on safe air pollution levels, aiming to mitigate the millions of premature deaths and loss of healthy years caused by air pollution. In Africa alone, air pollution was responsible for 1.1 million deaths in 2019, with over 28,000 premature deaths recorded in Ghana, predominantly attributed to vehicular emissions [20]. Legislation plays a crucial role in controlling environmental hazards, dating back to the earliest days of public health. While legislation can take various forms, including emission regulations and taxation on harmful activities, its effectiveness hinges on robust implementation and enforcement[21].Despite the existence of some laws and regulations addressing air pollution in Ghana, air quality continues to deteriorate, especially in developing countries like Ghana. Nations must take swift and collective action to combat air pollution. Strengthening air quality laws and regulations represents a pivotal policy action to significantly enhance air quality. While individual and group efforts to address air pollution are commendable, emphasis must be placed on countries with well-established legislative frameworks that effectively address environmental challenges[22]. Ghana can learn from these examples and adapt measures to protect human life, health, and well-being in the country.

III. EVOLUTION OF VEHICLE EMISSION STANDARDS IN THE UNITED STATES AND CALIFORNIA: A COMPREHENSIVE OVERVIEW

3.1 Evolution in the USA

The regulation of vehicular emissions in the United States is a multifaceted process governed by legislative mandates such as the Clean Air Act (CAA) and subsequent amendments, along with executive regulations managed by agencies like the Environmental Protection Agency (EPA) and the National Highway Traffic Safety Administration (NHTSA). These regulations address various pollutants emitted by motor vehicles, including carbon monoxide (CO), NO_X, and PM, while also incorporating fuel economy standards[23]. The Clean Air Act, initially enacted in 1963 and amended in 1977, provided the framework for establishing federal standards for vehicle emissions and introduced measures like vehicle inspection and maintenance programs. California, with its unique air quality challenges, has been granted authority to set its own emissions standards, which other states may choose to adopt[23]. The collaboration between federal and state regulators aims to establish stricter national emissions standards, with the EPA adopting California's fuel economy and greenhouse gas standards as a national standard by the 2016 model year. Compliance with these standards is ensured through rigorous testing procedures, including driving cycles that simulate typical driving patterns, to reduce harmful emissions and improve air quality nationwide[23], [24].

3.3 Regulation of Vehicular Emissions: A Comparative Analysis of Policies in the United States and Singapore

In the United States, the regulation of vehicular emissions has evolved over time, with standards set by legislative mandates like the Clean Air Act and administered by agencies such as the Environmental Protection Agency (EPA) and the National Highway Traffic Safety Administration (NHTSA). The transition from Tier I to Tier II standards, spanning from 1994 to 2009, marked a shift from weight-based emissions to a system of numbered "bins" to classify vehicles based on their emission levels[25]. Furthermore, regulations were imposed on the sulphur content in gasoline and diesel fuel to ensure compatibility with advanced exhaust treatment systems. Similarly, in Singapore, the National Environment Agency (NEA) mandates exhaust emission and fuel quality standards for all vehicles to mitigate air pollution and protect public health. This includes adherence to Euro VI emission standards for both new and used imported vehicles[26]. These regulatory frameworks underscore the importance of stringent measures to combat

vehicular air pollution and its adverse impacts on environmental and public health.

3.3.2Regulation of Vehicular Fuel Quality and Emissions in Singapore

In Singapore, stringent regulations govern vehicular fuel quality and emissions, ensuring that every vehicle operates with EURO V diesel or petrol meeting prescribed standards. Additionally, the implementation of Vehicle Emission Schemes (VES) aims to incentivize cleaner vehicle purchases through rebates or surcharges based on emission levels. These schemes, categorized by registration dates, offer a comprehensive framework for promoting environmentally friendly transportation choices. According to the Singapore government scheme on Carbon Emission-Based Vehicle Scheme (CEVS) and its revised version which aim was to assessvehicles based on their carbon dioxide (CO_2) emissions, encouraging the adoption of low-emission models. These schemes play a pivotal role in shaping vehicle choices, promoting cleaner transportation options, and ultimately contributing to environmental sustainability efforts [23].The Vehicle Emission Scheme (VES) in Singapore, implemented from February 2018 onwards, represents a comprehensive strategy aimed at mitigating harmful vehicle emissions. Initially focusing on carbon dioxide (CO_2) emissions along with three other pollutants—Hydrocarbons (HC), CO, and (NO_X)—the scheme assessed vehicles registered from February to June 2018 based on the worst-performing pollutant-determining corresponding VES rebates or surcharges[22].

3.5 Regulatory Approaches to Mitigating Vehicular Air Pollution: Lessons from Singapore and the United States

The regulatory measures outlined in both Singapore and the US demonstrates effective strategies for mitigating vehicular air pollution and promoting environmental sustainability. Singapore's strict regulations on idling engines, coupled with its VES, have led to tangible reductions in vehicular emissions and environmental degradation[27]. Similarly, the US's Clean Air Act, along with the establishment of National Ambient Air Quality Standards (NAAQS), has significantly reduced harmful air pollutants, resulting in improved public health and environmental outcomes. Emulating these successful regulatory frameworks in Ghana could yield substantial benefits by addressing the country's growing concerns regarding vehicular air pollution[17]. By adopting tailored legislation and enforcement mechanisms, Ghana could mitigate the adverse effects of pollution, enhance public health, and contribute to the attainment of sustainable development goals.

IV. CONCLUSION AND RECOMMENDATION

In conclusion, the regulatory frameworks implemented in Singapore and the US have demonstrated significant success in reducing vehicular air pollution and its associated environmental and health impacts. Through measures such as emission standards, VES, and regulations against idling engines, these countries have effectively curbed harmful emissions, leading to improved air quality and public health outcomes. The collaborative efforts between government agencies, stakeholders, and the public have been instrumental in driving these initiatives forward.

Building on these successes, there are several recommendations for other countries, such as Ghana, facing similar challenges with vehicular air pollution. First, Ghana could adopt and adapt some of the regulatory measures implemented in Singapore and the United States to its own context, considering factors such as vehicle fleet composition, infrastructure, and regulatory capacity. Additionally, public awareness campaigns and stakeholder engagement should be prioritized to foster a culture of environmental responsibility and compliance with regulations.

Furthermore, investments in green technologies and sustainable transportation infrastructure, such as electric vehicles and enhanced public transportation systems, can contribute to long-term reductions in vehicular emissions. Lastly, collaboration with international partners and organizations can provide valuable expertise and resources to support Ghana's efforts in mitigating vehicular air pollution and advancing sustainable development goals. By implementing these recommendations, Ghana and other developing countries can make significant strides towards improving air quality, protecting public health, and achieving environmental sustainability.

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