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Implementation of Car-Free Days in Support of Sustainable Development to Reduce Vehicle CO_2 Emissions in Urban Areas

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Abstract

The transportation sector is one of the main contributors to global greenhouse gas emissions, accounting for 18.52% of total emissions, with this percentage reaching 40% in developed countries. This research aims to assess the effectiveness of Car-Free Day (CFD) implementation in reducing emissions in Cirebon, Indonesia, as a contribution to the 13th Sustainable Development Goal on climate action. The research method used a mixed approach, combining quantitative analysis of fuel consumption data with qualitative interviews to gain a comprehensive understanding of the impact of CFD. Referring to the Ministry of Environment and Forestry's National Greenhouse Gas Inventory guidelines, Book I: The results showed that while CFD reduced emissions by 13-26% in the designated lane due to traffic diversion, it also led to an 8-14% increase in emissions in the alternative lane. Therefore, the overall emission reduction effort was not optimal, as the emission reduction in one lane was masked by the emission increase in the other lane. The implication of this research is that a more holistic approach is needed to effectively reduce urban greenhouse gas emissions. The results of this research can serve as a basis for formulating more effective transportation policies, such as extending the duration and coverage of CFD, restricting vehicles on alternative routes, and improving public transportation systems that are more environmentally friendly.

Keywords: Car Free Day, Greenhouse Gas Emissions, Transportation.

INTRODUCTION

Climate change caused by increasing greenhouse gas (GHG) concentrations in the atmosphere is one of the most pressing global challenges of this century (Patrianti et al., 2020). In response to this challenge, the 2030 Agenda for Sustainable Development initiated by the United Nations (UN) emphasizes the importance of reducing GHG emissions to achieve environmentally friendly and sustainable development (Widyastuti, 2019). One of the main sectors contributing to the increase in GHG emissions is the transportation sector, which in 2016 accounted for 18.52% of total global GHG emissions. In fact, in developed countries, this sector can contribute more than 40% of the total emissions (Crippa et al., 2022). In addition, according to the International

Energy Outlook 2011, global fossil fuel consumption is projected to continue to increase, reaching an estimated 770 quadrillion BTU in 2035, more than double the consumption in 1990 (Studies, 2024). Therefore, appropriate and coordinated measures are needed to reduce the environmental impacts caused by the transportation sector, especially in developing countries such as Indonesia (Kasipillai & Chan, 2008); (Shahid et al., 2014); (Ali, 2013).

The transportation sector, which contributes about 25% to total global carbon dioxide (CO2) emissions (Agency, 2009), is a major concern in GHG emission reduction efforts. In Indonesia, the urban transportation system has grown rapidly, but this has also brought adverse impacts on air quality and public health. Road transportation, the main mode in Indonesia, contributes more than 90% to the country's oil consumption and GHG emissions, with emissions including CO2, methane (CH4), nitrous oxide (N2O), carbon monoxide (CO), hydrocarbons (HC), and particulate matter (PM) (Azhaginiyal & Umadevi, 2014). Although sea and air transportation also contribute to emissions, road transportation remains the main contributor, accounting for about 91% of total transportation sector emissions (Raihan, 2023).

At the city level, many areas in Indonesia, including Cirebon, are experiencing a significant increase in carbon emissions along with rapid urbanization and growth in the number of vehicles. Cirebon City, with a population of 348,912 by mid-2023, has experienced a significant spike in the number of vehicles, which in turn exacerbates the air pollution problem. This poses a major challenge for the local government in its efforts to create a more environmentally friendly city. In response to the growing air pollution problem, the Indonesian government through the “Langit Biru” program stipulated in Ministerial Decree No. 15/1996 seeks to reduce air pollution from both fixed and mobile sources. One important component of this program is the implementation of Car Free Day (CFD), which aims to reduce CO2 emissions from motor vehicles in urban areas.

This study aims to assess the effectiveness of the Car Free Day (CFD) program implementation in reducing vehicle CO2 emissions in Cirebon, a city with a rapid urbanization rate and a significant increase in the number of vehicles. The CFD program is expected to contribute to the achievement of Sustainable Development Goals, particularly Goal 13 on Climate Change Control, by reducing emissions from road transport. In addition, this study aims to explore the potential of CFD to improve air quality and reduce air pollution levels, and to identify factors that influence the success of the program. This research is important because it is expected to provide useful data and analysis for formulating more environmentally friendly urban transportation policies in the future.

In the context of previous research, there are several studies that assess the effect of Car Free Day policies on emissions and air quality. Research by (Mughal et al., 2021) in Singapore showed that CFD can significantly reduce CO2 emissions in areas where it is implemented. However, (Ramachandra, 2009) in his research in India revealed that although CFD contributes to emission reductions in the areas it passes through, traffic diversion to alternative routes may reduce the effectiveness of this program in the long run. Another study by (Martos et al., 2016) indicated that the success of CFD depends not only on vehicle restriction policies, but also on public participation in switching to environmentally friendly modes of transportation. Therefore, this study has an urgency to deepen the understanding of the challenges and opportunities that exist in the implementation of CFD in Indonesia's cities, especially Cirebon, which is growing rapidly.

The novelty of this study lies in its approach that examines the direct impact of CFD implementation on CO2 emissions and air quality in Cirebon, as well as identifying local factors that influence the success of the program. Although CFD has been implemented in various major cities around the world, there is limited research examining its effectiveness in small or medium-sized cities in Indonesia, which have different social and economic characteristics. Therefore, this study is expected to make a new contribution to the development of more sustainable transportation policies in Indonesia.

Based on the above background, the main objective of this study is to evaluate the impact of Car Free Day program implementation on reducing CO2 emissions and improving air quality in Cirebon. Specifically, this study aims to measure changes in the concentration of CO2 and other air pollutants during the implementation of CFD and compare it with normal days, as well as identify factors that affect the effectiveness of the program. The benefits of this study are expected to provide policy recommendations for the Cirebon city government and the Indonesian government in formulating more environmentally friendly and sustainable transportation programs. In addition, the results of this study can also serve as a reference for other cities in Indonesia that want to implement similar policies to reduce emissions and improve their air quality.

METHOD

Data Collection Techniques and Sources

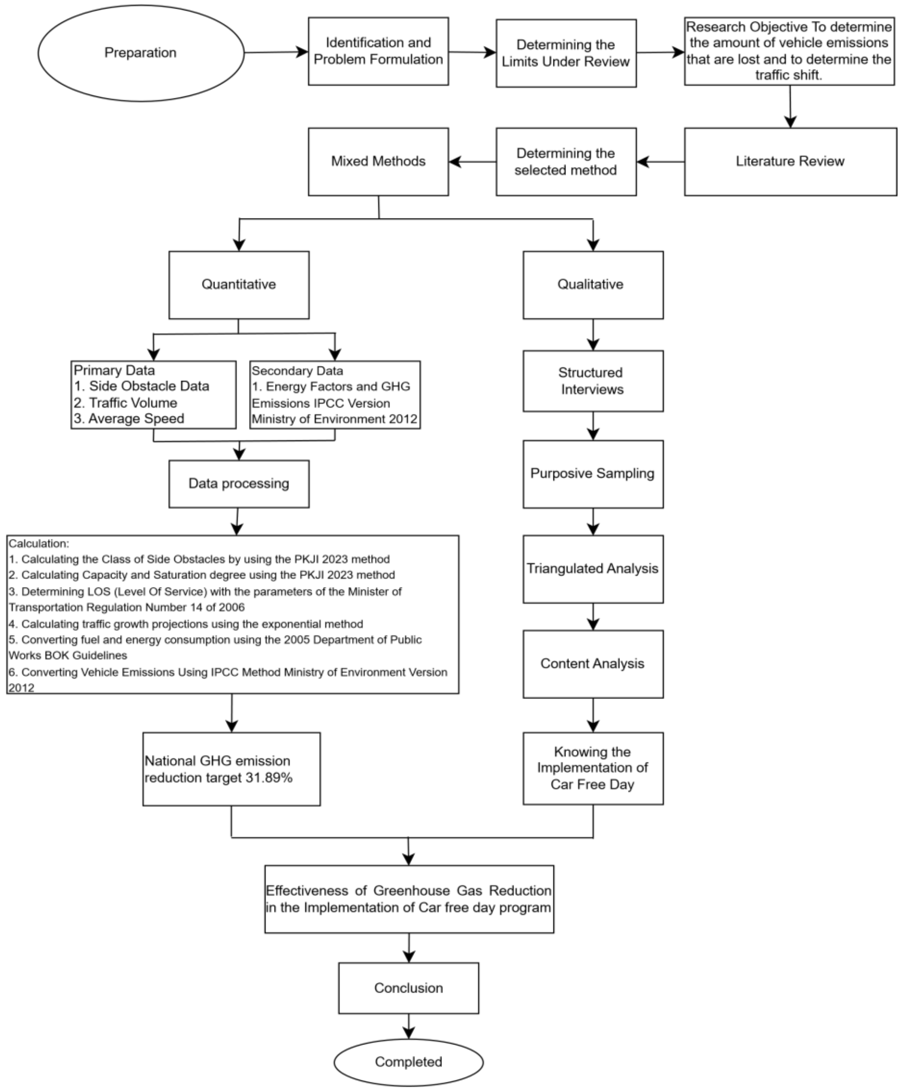

Figure 1. Research Method

This research study utilizes a mixed methods design, which combines quantitative and qualitative research approaches. This methodological framework allows for a more nuanced understanding of the research phenomenon by integrating both numerical and textual data. Qualitative data serves as a vital complement to quantitative data, providing richer insights into the research problem. Both primary and secondary data will be collected for this study.

This research aims to evaluate the performance of a selected road section by analyzing key performance indicators such as free-flow speed, road capacity, degree of saturation, and level of service. Furthermore, the study seeks to quantify greenhouse gas emissions generated from vehicular activities. Primary data collection involved on-site surveys to identify road sections, assess roadside obstructions (e.g., illegal parking, street vendors), and measure traffic characteristics. Supplementary data, including greenhouse gas emission factors from the IPCC version issued by the Ministry of Environment in 2012 [18] (Eggleston et al., 2006), was integrated with primary data to estimate total greenhouse gas emissions.

Table 1. Primary Data Requirements for Traffic Engineering Analysis

No.	Data	Source
1.	Side Obstacle Data	Survey
2	Average daily traffic volume	Survey
3	Average Speed	Survey
4	Interview	Survey

Research Area and Its Characteristics

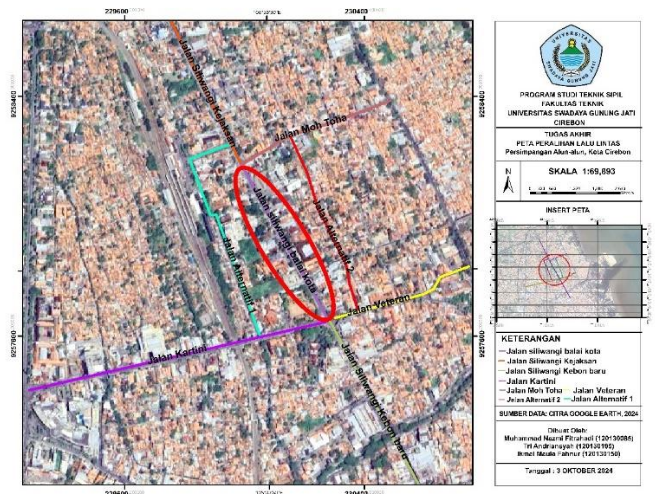

Figure 2. Survey Site at Alun-alun Square Junction, Cirebon

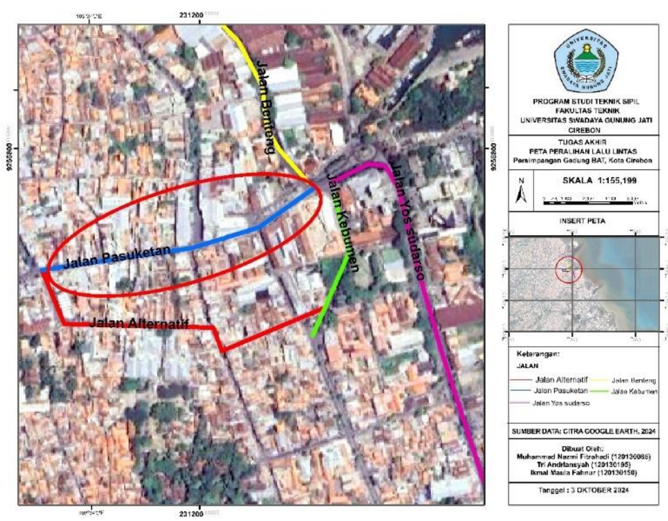

Figure 3. Survey Site at BAT Building Junction

Table 2. Secondary Data Needs for Road Usage Phase

No.	Data	Source
1	IPCC Ministry of Environment 2012 Energy Consumption and GHG Emission Factors Database	Ministry of Environment. National Greenhouse Gas Inventory Implementation Guidelines, Volume I: General Guidelines. MoE, Jakarta, 2012.

Table 3. Road Name

Road Name	Lane Width (m)	Number of Lanes	Road Width (m)	Road Shoulder (m)	Directi on	Road Length (m)
Pasuketan road	4	2	8	2.5	1	500
Benteng Road	3.5	4	14	0.6	2	550
Yos Sudarso road	4	4	16	0.6	2	700
Kebumen road	4.75	2	9.5	3	2	200
Siliwangi Balai Kota Road	3	4	12	3	2	600
Kartini road	6.5	2	13	4	2	1000
Siliwangi Kebon Baru Road	3	4	12	3	2	450
Veteran road	5	2	10	4	2	470
Moh Toha road	4.8	2	9.6	3	2	500
Siliwangi Kejaksan road	3	4	12	3	2	700

Calculation Methodology

A crucial first step in calculating emissions is to determine the fuel consumption of a vehicle. The more fuel a vehicle consumes, the greater the amount of pollutants it releases. Therefore, accurate fuel consumption data is essential for precise emission calculations. With accurate data, we can predict environmental impacts and effectively compare the emission levels of various vehicles (Rizki et al., 2020). As a reference, guidelines such as the 2005 Department of Public Works Vehicle Operating Cost Calculation can be used to calculate fuel consumption (Umum, 2005). To obtain a reliable estimation of fuel consumption, comprehensive data is required, including average derivative, average acceleration, standard deviation of acceleration, and vehicle weight. This data enables us to construct a more accurate predictive model by considering various factors that influence fuel consumption (Faris et al., 2011).

The calculation of greenhouse gas emissions from the transportation sector is commonly classified into three tiers: Tier 1, Tier 2, and Tier 3. Tier 1 calculations employ default global emission factors as specified by the IPCC 2006. Tier 2 refines these calculations by incorporating region-specific emission factors, such as those applicable to Indonesian fuel characteristics. Tier 3 represents the most granular level of analysis, requiring vehicle-specific emission factors determined through the use of emission analyzers (Sim & Sim, 2017). This study adopts the Tier 1 approach, utilizing the IPCC 2006 default emission factors.

The Tier 1 emission calculation method offers several advantages, including simplicity, relatively low cost, consistency, and ease of understanding. However, this method also has limitations, notably its lower accuracy compared to more refined methods. Additionally, the information generated by Tier 1 is less detailed, making it challenging to identify specific emission sources and their associated production processes. Despite these limitations, the Tier 1 method is frequently employed as a baseline for emission calculations. A common equation used in Tier 1 to estimate CO_2, CH_4, and N_2O emissions from road vehicles is as follows:

Tier-1 Emissions CO_2, CH_2 dan N_2O Road transportation

$$\textbf{Emission} = \sum_{a} \textbf{consumption } BB_a * \textbf{Emission factor}_a$$

Description:

Emissions	: Emissions CO_2, CH_4 atau N_2O
consumption BB_a	: Fuel consumed = sold
Faktor $Emissions_a$	: CO_2, CH_4 ATAU N_2O emission factor by fuel type (kg gas/TI), default IPPC 2006
a	: Fuel Type (Premium, diesel)

RESULT AND DISCUSSION

Road Capacity Analysis

Road capacity calculations, based on traffic volume data and identified side constraints from field surveys, will be verified against the 2023 Indonesian Road Capacity Guidelines [20]. Adequate road capacity, as determined through these calculations, is crucial for reducing congestion and enabling vehicles to maintain steady speeds, thereby positively impacting fuel consumption and minimizing unnecessary maneuvers. Additionally, average acceleration (AR) can be estimated using the regression model AR = 0.0128 × (V/C), where V and C represent traffic volume and road capacity, respectively. This model highlights the significant influence of traffic congestion on average acceleration, demonstrating the importance of sufficient road capacity for efficient traffic flow.

a) Traffic volume

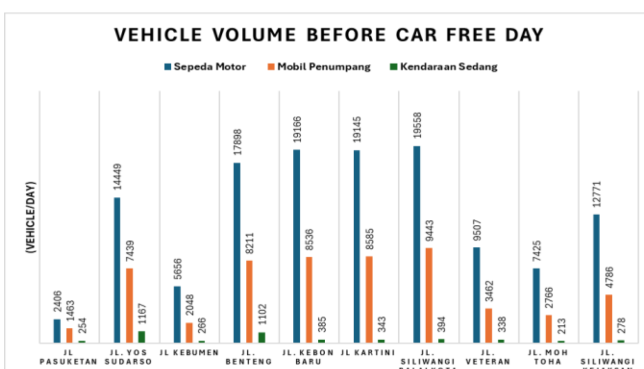

Figure 4. Traffic volume

Based on the data analysis in figure 4, it can be concluded that Pasuketan Road has a lower total traffic volume due to its one-way traffic flow, while Jalan Siliwangi-Balai Kota exhibits a higher total traffic volume compared to surrounding road sections. This indicates that Jalan Siliwangi-Balai Kota is one of the busiest road segments in the area.

b) Traffic Flow

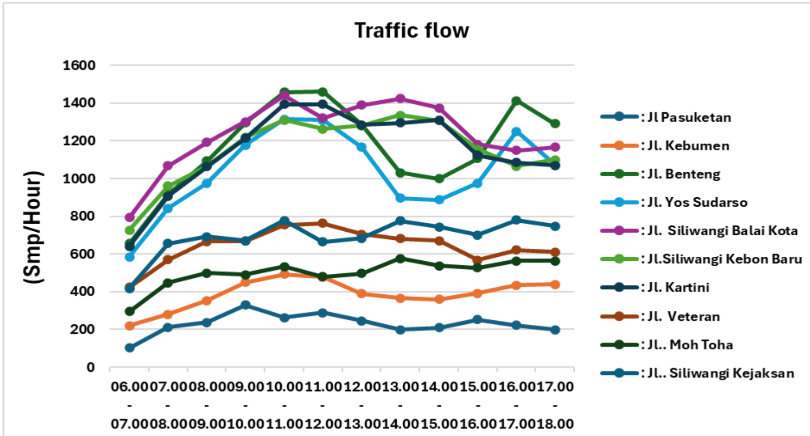

Figure 5. Traffic Flow

The analysis of traffic volume distribution, presented in figure 5, is expressed in passenger car units (pcu/hour). The initial data was converted using passenger car unit factors as outlined in the 2023 Indonesian Road Capacity Guidelines. The results show that Jalan Benteng records the maximum traffic volume of 1460 pcu/hour between 11:00 AM and 12:00 PM, while Pasuketan road records the minimum traffic volume of 101 pcu/hour between 6:00 AM and 7:00 AM.

c) Side constraints

Table 4. Side constraints

Side constraints		
Road Name	**Value of event frequency**	**KHS**
Pasuketan road	447.1	Medium (M)
Siliwangi Balai kota road	766.1	High (H)

The frequency of lateral obstructions was measured by counting the number of occurrences on each lane along a 200-meter stretch during a 12-hour observation period. Based on the measurements, the frequency of obstructions was found to be 447.1 times on Pasuketan Road and 766.1 times on Jalan Siliwangi-Balai Kota. According to the applicable classification, a frequency of 447.1 times is categorized as a medium level of obstruction, while a frequency of 766.1 times is categorized as a high level of obstruction.

d) Degree of Saturation and Level of service

Table 5. Degree of Saturation

Road Name	Traffic flow q SMP/hour	Degree of Saturation V/C ratio	Travel speed V_{MP} km/hour	Long Segment P km	Travel time W_T Hour	Level of Service (LOS)
Pasuketan road	328.800	0.2030	56.3	0.5	0.0089	A
Benteng Road	1460.600	0.5880	57.9	0.55	0.0095	A
Yos Sudarso road	1314.850	0.4856	51	0.7	0.0137	A
Kebumen road	492.400	0.1718	38	0.2	0.0053	A
Siliwangi Balai Kota Road	1441.650	0.5987	44	0.6	0.0136	A
Kartini road	1394.750	0.5395	44	1	0.0227	A
Siliwangi Kebon Baru Road	1335.750	0.5547	45.5	0.45	0.0099	A
Veteran road	764.000	0.2671	39	0.47	0.0121	A
Siliwangi Kejaksan road	780.300	0.3241	46	0.7	0.0152	A
Moh Toha road	577.200	0.2114	34.7	0.5	0.0144	A

The saturation analysis results showed that Siliwangi Balai Kota Road experienced the most severe congestion with a saturation index of 0.5987, while Pasuketan Road had the least congestion with a saturation index of 0.2030. However, despite these variations, all road segments evaluated were categorized as Level of Service A, indicating a generally satisfactory level of service on all studied roads, according to Ministerial Regulation Number 14 of 2006. Level of Service (LOS), which refers to the degree of comfort and ease experienced by road users, is strongly correlated with vehicular fuel consumption. Lower LOS values (indicating higher congestion levels) are generally associated with increased fuel consumption.

e) Traffic transition

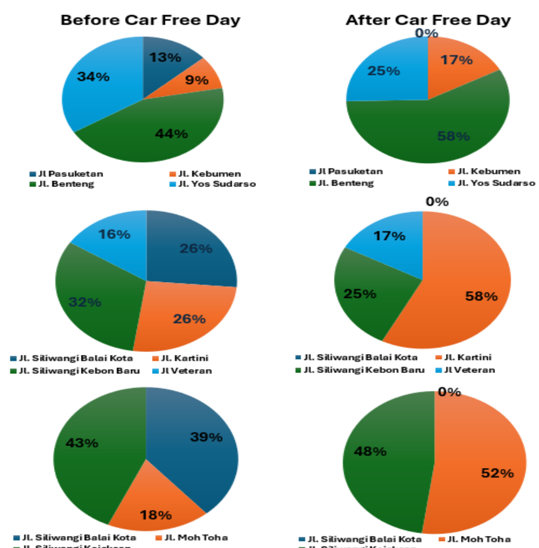

Figure 6. Traffic transition

The empirical data presented in Figure 6 underscores the substantial influence of the vehicle-free day policy on traffic distribution. For instance, the observed 8% increase in traffic volume on Jalan Kebumen and 14% on Jalan Benteng, accompanied by a 9% decrease on Jalan Yos Sudarso, is indicative of the public's response to the imposed traffic restrictions by seeking alternative routes. These findings provide compelling evidence that traffic management measures can effectively induce shifts in public mobility behavior.

f) Fuel consumption

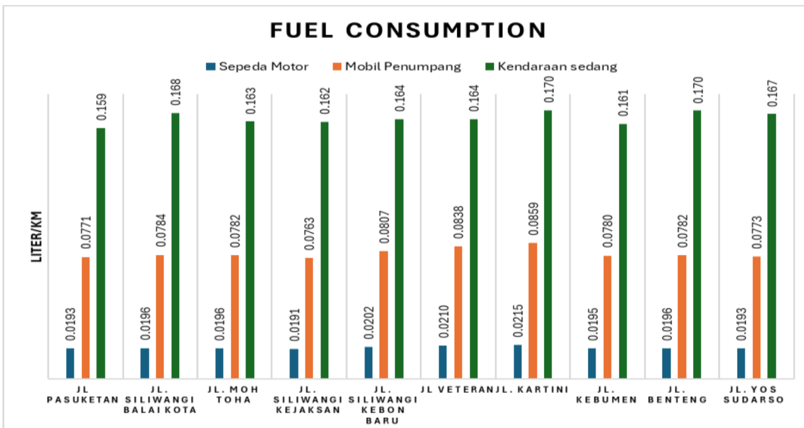

Figure 7. Fuel consumption

A recapitulation analysis of fuel consumption data reveals that road length has a direct correlation with fuel consumption. Longer routes lead to increased fuel consumption. Furthermore, acceleration patterns, specifically the variability in acceleration, also influence fuel efficiency. Vehicles maintaining a smooth and consistent acceleration rate exhibit lower fuel consumption compared to those experiencing frequent changes in speed.

g) Greenhouse Gas Emissions

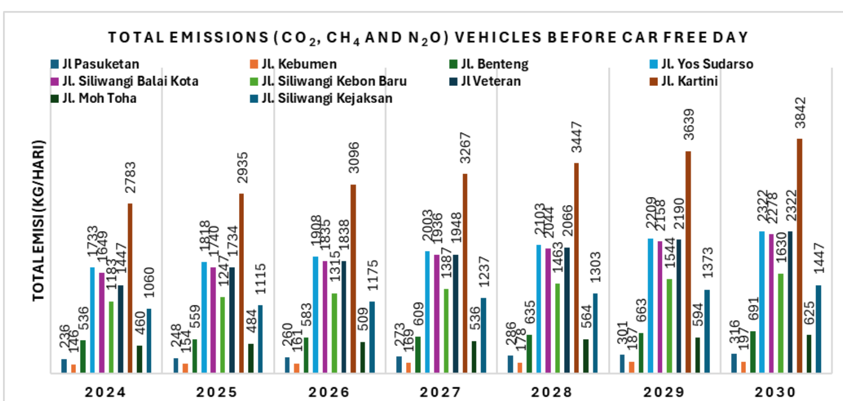

Figure 8. Total Greenhouse Gas Emissions Before Car Free Day

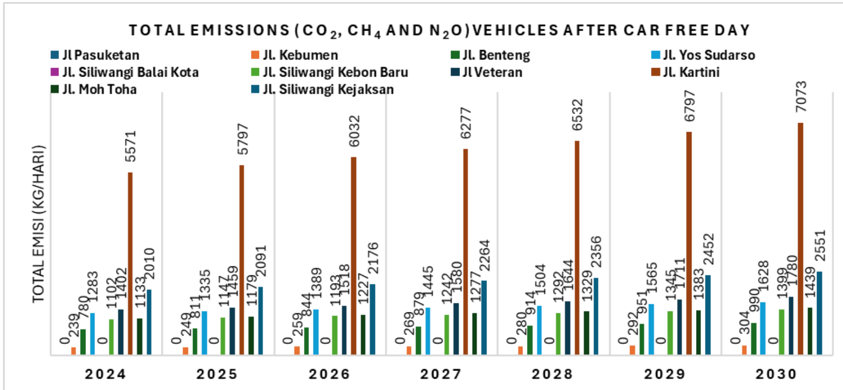

Figure 9. Total greenhouse gas emissions after Car free day

The analysis shows that the implementation of Car Free Day resulted in a 13%-28% reduction in average vehicle volume. However, traffic diversion led to a 4%-12% increase in vehicle volume on alternative routes, causing a corresponding increase in greenhouse gas emissions. Specifically, exhaust emissions on Banteng Street increased by 167,640 kg/day, from 440,187 kg/day to 607,827 kg/day, while emissions on Veteran Street increased by 46,823 kg/day, from 214,114 kg/day to 260,937 kg/day.

h) Projections Over the Next Six Years

This study seeks to project the future increase in greenhouse gas emissions driven by growing traffic volume, in the context of SDGs 11 and 13. Using an exponential growth model and data from the Cirebon City Transportation Agency, which estimates a 4.1% annual increase in traffic volume, we have forecasted vehicle emissions. The results, visualized in Figure 7 and Table 6, can inform the development of comprehensive strategies to address both sustainable urbanization and climate change mitigation.

Table 6. Projected Greenhouse Gas Emissions

Total Vehicle Emissions (CO_2, CH_4, and N_2O)														
Year	**2024**		**2025**		**2026**		**2027**		**2028**		**2029**		**2030**	
Road Name	None CFD	CFD	None CFD	CFD	None CFD	CFD	None CFD	CFD	None CFD	CFD	None CFD	CFD	None CFD	CFD
Pasuketan road	242	0	254	0	266	0	280	0	294	0	309	0	324	0
Kebumen road	146	239	154	249	161	259	169	269	178	280	187	292	197	304
Benteng Road	560	812	584	845	609	879	635	915	662	952	691	991	721	1031
Yos Sudarso road	1815	1344	1904	1398	1999	1455	2098	1514	2204	1576	2315	1639	2433	1706
Siliwangi Balai Kota road	1736	0	1831	0	1931	0	2038	0	2151	0	2271	0	2398	0
Siliwangi Kebon Baru road	1242	1157	1310	1204	1381	1253	1457	1304	1537	1357	1622	1412	1712	1469
Veteran road	1494	1436	1784	1495	1891	1555	2005	1619	2126	1684	2255	1753	2391	1824
Kartini road	2783	5571	2935	5797	3096	6032	3267	6277	3447	6532	3639	6797	3842	7073

Total Vehicle Emissions (CO_2, CH_4, and N_2O)														
Year	2024		2025		2026		2027		2028		2029		2030	
Moh Toha road	460	1133	484	1179	509	1227	536	1277	564	1329	594	1383	625	1439
Siliwangi Kejaksan road	1101	2089	1160	2174	1221	2262	1286	2354	1355	2450	1428	2549	1505	2652
Jumlah	11579	13782	12398	14342	13065	14924	13771	15529	14518	16160	15310	16815	16148	17498

The quantitative data in Table 6 demonstrates a consistent upward trajectory in vehicle exhaust emissions, correlating with the increasing traffic volume. The year 2024 exhibits an anomaly, with emissions during Car Free Day being 19% higher. However, a trend analysis from 2025 to 2030 suggests a decreasing rate of increase in emissions, albeit with a continued absolute rise.

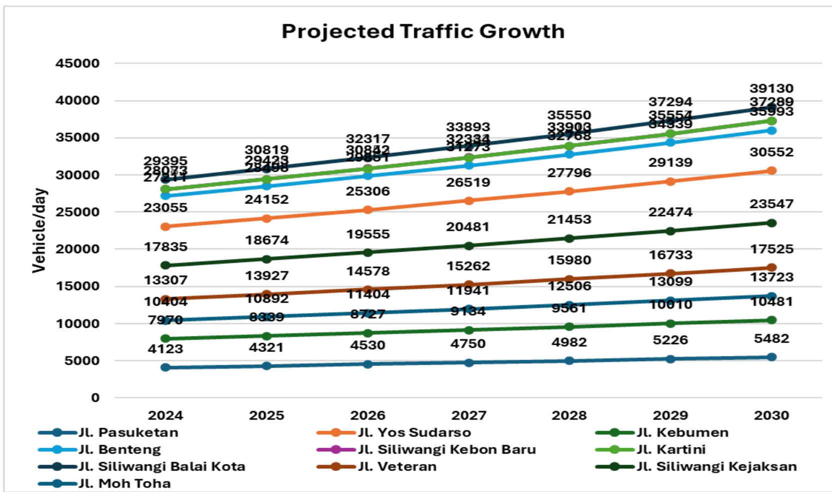

Figure 10. Future Greenhouse Gas Emissions Forecast

i) Interview

In-depth interviews were conducted with three experts in their respective fields: Indra Setiaman from the Department of Transportation, Rasyiid Rantau Pamungkas and Ahmad Maulana Aziz from the Department of Environment, and experts or academics Dr. Aria Mariany S.T., M.T. The findings from these interviews, after thorough analysis, are tabulated below.

Table 7. Content Analysis

Question	Department of Transportation	Department of Environment	Experts/academics	Conclusion
Purpose of Car Free Day	reduce CO gas on roads that according to the measurement results from DLH have high CO gas.	reduce motor vehicle pollution, and improve the healthy life of the community	reducing people's use of vehicles	The purpose of Car Free Day is to reduce the use of vehicles, which are emitters of CO_2 gas.

Question	Department of Transportation	Department of Environment	Experts/academics	Conclusion
Government policies to reduce greenhouse gases, other than CFDs	The new government policy is electric vehicles, but until now there has been no regulation on the highway from the center for these electric vehicles.	Development of environmentally friendly transportation because 45% of Emissions from transportation and increase Green open space	Increase public transportation and plant trees for shade and CO_2 absorption.	Policies to reduce greenhouse gases development of environmentally friendly transportation and also create green open spaces
challenges in implementing the Car Free Day	The location is very difficult to do in accordance with the DLH study because it is constrained by disturbing surrounding activities.	Moving from dishub to lh, not maximizing the flow transition, air quality tests have not been carried out.	people come there also use vehicles and people's habits are also not to reduce Emissions but to go for a walk.	Challenges include community disruption, insufficient air quality testing, and public resistance to reducing emissions
impact on the surrounding economy	No economic impact is affected as it is conducted in the morning.	The economic impact is not significant because the CFD is from 6-9, there is an appeal to businesses, but it opens at 9 o'clock.	economic impact is not affected much due to the short period of implementation	No significant impact due to short time
How significant is the influence of Car Free Day	When viewed from the implementation time of 6am-9am, the decrease is very insignificant.	Ineffective implementation due to insufficient road infrastructure	insignificant due to non-compliant road sections	Car Free Day does not significantly reduce Emissions due to short time and unsuitable road sections.

In line with the global Sustainable Development Goals (SDGs), the Cirebon City Government has launched the Car Free Day initiative to contribute to the national goal of reducing Greenhouse Gas (GHG) emissions by 31.89%, as stated in the Cirebon Mayor's Circular Letter No. 510.11/SE.02-DLH. The Transportation Department emphasized that the main objective of the program is to reduce emissions on designated roads (Dewi, 2014).

Several studies have shown that initiatives such as Car Free Day can lead to short-term reductions in air pollution and emissions, especially in urban areas with high traffic volumes. For example, research by (Rahmawati & Pratama, 2023) found that temporary vehicle restrictions in several Southeast Asian cities resulted in a fairly significant reduction in CO2 levels during Car Free Day. Likewise, (Romadhani et al., 2024) concluded that urban traffic restrictions can bring significant air quality improvements if combined with public awareness campaigns and supportive infrastructure.

However, despite the potential benefits, the implementation of Car Free Day in Cirebon City did not show a significant impact on reducing overall greenhouse gas emissions. Based on the research findings, although the program managed to reduce emissions by 13-26% on roads designated as vehicle-free zones, a significant increase in emissions was found on alternative routes, with an increase of 8-14%. This unintended consequence is related to traffic shifting that has been noted in other studies, such as the one by (Amalia, 2017), which observed the shifting of pollution levels from restricted areas to less congested roads, leading to insignificant long-term impacts on total emissions. Therefore, the government's target of 31.89% emission reduction has not been achieved.

The Cirebon City Environmental Agency also expressed the need for improvements in the implementation of Car Free Day, particularly in terms of expanding the network of closed roads and implementing stricter guidelines. This sentiment is in line with findings from global studies that emphasize the importance of integrating broader urban mobility strategies. For example, a study by (Joga, 2017) showed that the success of car-free initiatives depends not only on reducing vehicle traffic, but also on providing sustainable transportation alternatives such as bicycle lanes, better public transportation, and pedestrian-friendly spaces.

The study concluded that a more diversified approach is needed to effectively reduce greenhouse gas emissions in the region. Based on the existing Car Free Day program, the researcher suggests that the local government adopt the recommendations of Dr. Aria Mariany S.T., M.T. to develop a more comprehensive policy, including promoting sustainable transportation systems and expanding green spaces. Previous research by (Megawati et al., 2024) supports this, noting that cities that integrate green infrastructure and multi-modal transportation systems experience more significant emission reductions compared to cities that rely solely on restrictive measures such as Car Free Day.

CONCLUSION

Conclusions from the findings of the analysis of 10 road sections show that the implementation of the Motor Vehicle Free Day had mixed impacts on traffic flow and greenhouse gas emissions. While the initiative aims to reduce emissions on closed roads, the overall result is an increase in emissions due to traffic diversion. For example, roads such as Jalan Kebumen and Jalan Benteng experienced significant traffic spikes, while alternative routes experienced higher congestion, ultimately reducing traffic efficiency. The success of the Hari Bebas Bermotor initiative in reducing emissions is undermined by such traffic diversions, as increased vehicle activity on surrounding roads offsets the benefits gained from road closures.

This research contributes to a deeper understanding of the unintended consequences of such environmental initiatives and highlights the need for more comprehensive planning. In the future, further research could explore strategies to improve the effectiveness of the Car Free Day, such as optimizing road closures or encouraging alternative modes of transportation. The findings also suggest that future policy adjustments could focus on long-term traffic management solutions and urban planning, to ensure that the ultimate goals of reducing emissions and congestion are achieved.

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