1. Introduction

According to the Intergovernmental Panel on Climate Change [1] global greenhouse gas (GHG) emissions climbed 70% from 1970 to 2004, with CO₂ being the primary emitted gas. Emission load significantly increases in quantity due to population explosion, anthropogenic activities, combustion of fossil fuels, and changes in green areas. In the transportation sector, greenhouse gases such as carbon dioxide, methane, and nitrogen oxides are emitted from fuel combustion in motor vehicles or other mobile sources [2]. Fuels are widely used to power motor vehicles, and energy consumption contributes 75% to CO₂ emissions. According to the Indonesia Ministry of Energy and Mineral Resources, fuel is still the primary source of energy (49.5%), followed by coal, gas, water resources, geothermal, and
renewable energy, and the national fuel consumption has shown an increasing trend since 2000. There are various factors affecting the number of emissions generated by a motor vehicle, such as the type and volume of fuel and road characteristics [3].

The Covid-19 pandemic is an infectious disease that is currently affecting the world population. An outbreak was first reported in Wuhan City, Hubei Province, China, in December 2019, and was announced as a pandemic by the World Health Organization (WHO) on March 11, 2020 [4]. The pandemic is unexpectedly affecting the environment. The closure of borders and international travel bans have changed consumption patterns and reduced transport use. Compared with the 2019 mean level, the daily global CO$_2$ emission decreased by -17% (-11 to -25% for ±1σ) in early April 2020, just below half of the change in transport use. Government actions and post-crisis economic incentives are likely to affect global CO$_2$ emission pathways for decades [5].

Preliminary studies showed that there had been a decrease in emissions from the transportation, LPG, and electricity sectors during the March–November 2020 pandemic in several cities in Indonesia. The results showed a 33% reduction in emissions from the transportation sector [4]. Unlike other cities, the transportation sector in Yogyakarta is supported by the number motorcycles and tourist vehicles. It is synonymous with the icon of Yogyakarta as a Student City and Tourism City. Pandemic conditions that lasted for almost two years forced the education sector to be conducted online and the tourism sector stopped. The resulting consequence, namely the number of vehicles on the streets of Yogyakarta city will decrease and will logically reduce emissions from the transportation sector.

Since WHO declared the COVID-19 pandemic in March 2020, many countries, including Indonesia, have implemented local to national restriction policies for social activities and gatherings (lockdown). Several countries experienced a significant reduction in carbon emissions, especially in urban areas in the Southeast Asia region [6]. According to [7], stated that the reduced emissions were caused by a decrease in activities in the transportation sector. Based on this background, the research was intended to answer the question: How does the Covid-19 pandemic affect carbon emissions from the transportation sector in the Special Region of Yogyakarta?

2. Method
2.1. Data collection and analysis

The required data, or research objects, included fuel consumption, fuel sales, activities in the transportation sector, road section, and road density derived from the Transportation Department’s CCTV records and BPS-Statistics Indonesia. Fuel sales obtained from PT Pertamina, a state-owned oil and natural gas corporation in Indonesia, were used to determine fuel consumption, which was then converted into emissions. Fuel consumption data were collected through interviews with vehicle owners using Google Forms. Samples were selected randomly from local families who were working from home (WFH). The Covid-19 - Google Global Mobility Report was used to map trends of changes in respondents’ activity and mobility.

Carbon emission was quantified using the IPCC Calculation formula. The basic method of emissions inventory is by calculating emission load estimates without measuring ambient air quality directly but incorporating data on activities and emission factors. Calculation of motor vehicle emissions was done using the basic formula presented below:

$$CO_2\text{ Emission} = EF \times AD \times \left(1 - \frac{CE}{100}\right)$$

CO$_2$ Emission = Greenhouse gas emissions (CO$_2$)
EF = Emission factor (kg particulates per kg fuels)
AD = Average fuel consumption (liter/year)
CE = Overall reduction/efficiency factor

Emission factors are determined based on research and are specific to each ingredient or product. The emission factor used was obtained from the standard guidelines issued in the Emission Inventory
Guidebook [8] and those by the IPCC. The pattern of fuel consumption among the community was determined with descriptive analysis, that is, by describing the questionnaire responses based on the mean value, percentage, and frequency.

3. Results and discussion

3.1. Road Sections in the Special Region of Yogyakarta
Traffic performance is an indicator of the quality of services provided by a particular road section that can be used to measure the level of congestion and traffic density and is expressed as the v/c ratio. The density of motor vehicles on the roads was calculated for each sub provincial unit. The road performances in Sleman and Yogyakarta were relatively the same, as indicated by the v/c ratio of 0.77. Kulon Progo and Gunungkidul also shared a similar road performance, with a v/c ratio of 0.36. Meanwhile, the road section in Bantul had a mean v/c ratio of 0.58.

Road densities in Sleman and Yogyakarta are higher than in other areas and that, overall, the road services in SRY are moderate. The research calculated motor vehicle density because the transportation sector is believed to be the largest contributor to annual CO$_2$, i.e., 60% of the total emissions. According to [9], the higher the motor vehicle density, the greater the exhaust gas emitted from the road section and, thus, the greater the CO$_2$ concentration.

3.2. CO$_2$ Emissions Based on Number of Motor Vehicles Before and During the Covid-19 Pandemic
CO$_2$ emissions from motor vehicles can be estimated with several approaches, for example, the number of motor vehicles. Here, the research variables were the number of motor vehicles before (2018 and 2019) and during the Covid-19 pandemic (2020). Supporting data were obtained from BPS-Statistics Indonesia, including the number of motorcycles, passenger cars, buses, and trucks. Figure 1 shows that the total registered motor vehicles in SRY continued to increase every year. Moreover, motorcycles were the most used vehicle. Trucks contribute the highest CO$_2$ emission among the vehicles observed, i.e., 774 g/km for each truck unit. Figure 2 shows the amount of CO$_2$ emissions of four motor vehicles in SRY and its sub provincial units that generally increased from 2018 to 2020. A decreasing trend, however, was detected in Sleman, from 10 million g/km in 2018 to 7.3 million g/km in 2020, and Kulon Progo from 35.7 million g/km in 2019 to 29.8 million g/km in 2020. Nevertheless, the total CO$_2$ emissions in SRY did not show a significant annual increase.

3.3. CO$_2$ Emissions Based on Fuel Consumption Before and During the Covid-19 Pandemic
In addition to the number of motor vehicles, the research also estimated CO$_2$ emissions from these vehicles using fuel consumption. As seen in Table 1, the data showed a decreasing trend in fuel consumption during the Covid-19 pandemic. From 2019 to 2020, the reduction was up to 74 kL/year.
Gasoline was the most widely used fuel because in the country gasoline-powered vehicles were more common and were sold at a relatively cheap price than diesel ones. However, diesel fuel has a higher emission factor than gasoline, meaning that it has a greater contribution to CO$_2$ emissions.

The emission factor according to the IPCC is expressed in units of emission per unit of energy consumed (kg/TJ). Based on the amount of CO$_2$, gasoline, or gasoline-fueled vehicle, released the most CO$_2$ because it was used in far more significant amounts than diesel fuel. From 2019 to 2020, there was an annual decrease of 169,865 tons of CO$_2$, signifying the influence of the Covid-19 pandemic on fuel consumption through the social and physical distancing policies imposed to curb the spread.

**Table 1.** Fuel Consumption and CO$_2$ Emissions Estimated in the Special Region of Yogyakarta in 2019 and 2020 (in kL/year).

| Fuel Types (Trade Names) | Fuel Consumption (kL) | Emissions (tons CO$_2$) |
|-------------------------|-----------------------|------------------------|
|                         | 2019 | 2020 | 2019 | 2020 |
| Gasoline (Premium, Pentalite, Pertamax, Pertamax Turbo) | 660  | 587  | 1,508,336 | 1,341,393 |
| Gasoil (Diesel Fuel, Dexlite, and Pertamina Dex) | 149  | 147  | 396,285  | 393,364  |
| Total                   | 808  | 734  | 1,904,621 | 1,734,757 |

Global environmental conditions in early 2020 during the pandemic were filled with governments implementing numerous policies to prevent the further spread of the diseases. Similar effects on the transportation sector and air quality in China’s urban areas have also been reported. According to [11], when the Covid-19 pandemic reached its most serious phase in China (February 2020), the energy consumption and CO$_2$ emissions from fossil fuel vehicles (the burning of gasoline and diesel fuel) and battery electric vehicles were at their lowest.

3.4. **Community’s Fuel Consumption Pattern in the Special Region of Yogyakarta Before and During the Covid-19 Pandemic**

The community’s fuel consumption data were obtained by distributing online questionnaires developed in Google Form. A total of 83 respondents were subdivided by place of residence into five groups: Bantul (39.8% of total respondents), Yogyakarta City (8.4%), Gunungkidul (2.4%), Kulon Progo (3.6%), and Sleman (45.8%). They comprised 29.3% male and 70.7% female and were primarily at the age of 15‒25 years (64 people), including the productive age group who were actively involved in employment and education and, thus, most likely required fuel consumption to mobilize. Seventy respondents used motorcycles (84.3%), while 13 others mostly drove cars to mobilize (15.7%); in other words, most respondents preferred motorcycles to cars as their means of transportation.
Based on their responses to the online questionnaire, 81.9% said that the WFH policy decreased fuel consumption. As seen in Figure 3, changes in the distance traveled per day before and when the policy was in effect indicate low mobility (particularly with motor vehicles). Of the 83 respondents, 39 normally traveled >15 km per day, but then only 11 were able to travel the same distance when the government enforced the policy. Furthermore, 12 respondents normally traveled 1–5 km per day, and this number increased to 22 after the policy enforcement. Based on Figure 4, the distance traveled by the respondent is directly proportional to the volume of fuel used (liters) per week.

The WFH policy affects the consumption or purchase of motor vehicle fuels. This is possible because human activities, gatherings, and mobility with motor vehicles decreased in frequency. This low mobility is indicated by changes in the distance traveled per day before and during the WFH policy enforcement. According to [12], there is a relationship between distance to the workplace, travel behavior, energy use, and CO₂ emissions. The distance between workplace and place of residence is the strongest factor affecting the amount of CO₂ emission generated by the working population. Further, commuting workers are especially associated with higher CO₂ emissions because they have to travel a relatively long distance, resulting in greater use of transportation and energy access.

3.5. Community’s Mobility Pattern During the Covid-19 Pandemic

The Covid-19 - Google Global Mobility Report charts trends in activity and mobility, compares respective changes in response to the Covid-19 pandemic with the normal condition. Figure 5 shows that community movement in transit stations, workplaces, grocery stores, pharmacies, recreation areas, and parks decreased starting mid-March and formed a sharp negative decline in April and May. The number of visits to train stations, bus stations, and airports had decreased by 53% since the period of April 4 until May 16 or since the government imposed the large-scale social activity restrictions (early April to late May). Until the end of July 2021, visits to transit stations continued to decrease and were 65% lower than the normal conditions after the government tightened the restrictions.

Community mobility or movement in retail and recreation areas, comprising the number of visits to restaurants, cafes, shopping centers, amusement parks, museums, libraries, and cinemas, showed a negative trend: a decrease of 37% from normal conditions from April 4 to May 16, 2020, and 27% at the end of July 2021. Meanwhile, mobility related to public spending for daily activities, medicines, and medical needs also decreased by 3% on July 29, 2021. However, there was no significant decline in this category because people kept looking for ways to meet their basic needs such as food/daily necessities and medicines.

Figure 5. Mobility Trends During the Covid-19 Pandemic in the Special Region of Yogyakarta [13]
3.6. Residential Mobility in the Special Region of Yogyakarta

Population mobility is a process that significantly affects urban regions. Travels or commutes from the urban to the suburban areas and all activities that follow have changed the perception of residential mobility. Based on the Covid-19 - Google Global Mobility Report, it was found that the residential mobility in SRY changed in line with the Covid-19 pandemic and the restrictions imposed to manage this crisis. The residential mobility rate in SRY tended to be high or above the baseline, which was 13% from May 20 to July 1, 2021 (Figure 6). Over time, it continued to increase even up to 25% on July 11, 2021.

Despite the restrictions, trends in residential mobility rates remained positive or above the baseline. It was observed that 13% more people lived and did activities at home compared with normal conditions before the pandemic. This was because the government appealed for all residents to perform all activities of educational, work, religious, and social purposes at home online or remotely using communication tools and technology to curb the spread of the Covid-19. As a comparison, research in India by [14], found changes in residential mobility rates from the basic percentage during pre-lockdown, while on lockdown, and after the restriction was lifted. Across India, compared with the initial/pre-lockdown percentage, the residential mobility increased by 24.1% during phase 1 lockdown and 16.3% during phase 4. These increases were because most people stayed at home when the social activity restrictions were in effect. The situations explained above indicate that the Covid-19 pandemic has affected the public residential mobility both on national and global scales.

4. Conclusion

This research results have explored the impact of COVID-19 on transportation sector in the Special Region of Yogyakarta (SRY). The fuel consumption in the Special Region of Yogyakarta (SRY) decreased during the Covid-19 pandemic. The working-from-home (WFH) policy decreases the consumption or purchase of motor vehicle fuels, which is attributed to the lowered frequencies in activities outside the house and the use of motor vehicles to mobilize. This study contributes to the academic literature on the impact of coronavirus on human activities with a specific focus on carbon dioxide emission from transportation sector.

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