Environmental benefit of public fleet fueled by LPG/Vi-Gas in Magelang City, Indonesia: A Simulation Study

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Abstract. This paper presents a simulation study on the utilization of LPG/Vi-Gas for public transport in Magelang City. Estimates of CO₂ reduction per year are calculated theoretically and based on data from NEDC experiences. Both of these methods show positive results, reducing CO₂ by theoretical calculations and comparing with NEDC experiences are 13.6 and 11 tons per year, respectively. In conclusion, the utilization of LPG/Vi-Gas for public fleets in Magelang city is feasible to be implemented as the Government's effort to reduce CO₂ emission from transportation sector.

1. Introduction
In recent decades, air pollution in big cities has caused anxiety for analysts and environmental stakeholders [1]. A decrease in air quality appears to be a logical compensation for industrial, household, and transport activity. Implementation of low technological standards, fuel quality, and less strict emissions thresholds cause pollution from evaporation and tailpipe. In Indonesia, air quality levels in several major cities such as Jakarta, Bandung, and Surabaya have proven far above the WHO standards [2].

Currently, Magelang is the city ranked 85th in Indonesia, with a population of more than 124 thousand people. Compared to Surabaya or Bandung with a population of more than 2 million, Magelang may be too small. However, with an area of 18.12 km², the population of Magelang is 6,864 and is ranked 20th nationwide (landscape of Magelang city is presented in Figure 1). The addition of population, expansion, and construction of houses and shopping centers, road widening, and tree felling are other reasons for the decline in air quality as the emission absorber becomes reduced. If the problem of pollution due to transportation is not planned from now, it is not impossible Magelang city will also experience problems like other big cities that have become the attention of stakeholders [3]–[7]. The presence of Transportation on Demand (ToD) such as Gojek and Grab also increase traffic density. Although ToD provides advantages for its users in terms of comfort and speed, in macro is the burden of energy. The need for fuel in the city with ToD services becomes larger which means it also contributes more exhaust emissions to the environment.
1. Current Status of Public Fleet

Around the year 2013, the Government of Magelang City implements city branding "A Million Flower City" to support tourism Borobudur Temple. Improved view of the city is expected to be able to improve visitor comfort. However, this city branding program has not been continued with the modernization of public fleet. Currently, connectivity in Magelang (residential, market, school, tourist spot, etc.) is served by 12 lines with more than 300 units of fleets. Unfortunately, the existing fleet is dominated by cars produced in the 2000s and earlier as presented in Figure 2. With vehicles powered by carburetor technology and poor maintenance, the trend is low fuel efficiency and high exhaust emissions.

1.2. Opportunity to Switch to Cleaner Fuel

In 2017, Pertamina as a state-owned company has completed a fuel station in Magelang with LPG for a vehicle called Vi-Gas. Previously, Pertamina has also implemented similar programs in Jakarta, Bogor, Surabaya, Denpasar, Yogyakarta, and several other big cities. The installation of the Vi-Gas dispenser in Magelang is expected to attract the interest of car owners in Magelang and surrounding areas to use

![Figure 1. Location and landscape of Magelang city taken from google map](image1)

![Figure 2. Photographic views of the existing condition of the public fleet in Magelang](image2)
Vi-Gas, whether implemented in a full dedicated or bi-fuel system, where Vi-Gas and Gasoline can be used interchangeably [8]. If car owners have not been interested to convert their cars to Vi-Gas independently because of conversion costs, the Government can implement a free converter kits program to public fleet owners, as has been practiced in several cities such as Jakarta, Bogor and Palembang [9]. Vi-Gas is chosen because the pressure in the tank is low (0.8-1.2 MPa) compared to CNG (20 MPa), so the required infrastructure investment is also relatively low. Although Vi-Gas is a mixed fuel of propane and butane with different densities, it forms a homogeneous mixture [10]. The carbon content of Vi-Gas lower than gasoline is also an opportunity to produce lower exhaust emissions.

1.3. Objective
Currently, environmental issues and reduction of Greenhouse Gas (GHG) emission may be more important than other automotive issues, as an effort to maintain the environmental sustainability. Therefore, the objective of this study is to estimate CO\textsubscript{2} reduction from the implementation of LPG/Vi-Gas for public fleet in Magelang City. The simulation was carried out with two models based on carbon equilibrium theory and based on the results of emissions testing from NEDC experiences.

2. Method
Learning from WLPGA’s annual report, there are two models of LPG applications for vehicles that convert existing vehicles by adding LPG kits and purchasing new vehicles already equipped with LPG kits [11]–[13]. The first model (convert existing vehicles by adding LPG kits) can be implemented at low cost, relatively. Converter and Mixer (CM) of LPG kits can be directly utilized even on carburetor engines. However, because it is applied to old vehicle technology, the resulting emissions are not as good as OEM products. In the second model, it generally uses Vapor Phase Injection (VPI) or Liquid Phase Injection (LPI) of LPG kits, which results in good engine performance as well as lower emissions. As a consequence, a much higher initial investment is needed. Therefore, the environmental benefits in this study are modeled in the first scenario, with consideration of much lower initial investment and can be implemented in the short-term.

3. Result and Discussion
3.1. Fleets Operational Data
Every year, the Department of Transportation of Magelang City conducts inspection and data collection on public transport. Data at the beginning of 2018 is presented in Figure 3. It is known that of the 335 units of the public fleet, only 306 units operate daily (about 91%). Then, of the 12 existing lines, each unit covered a distance average of 137 km per day.

Figure 3. Public fleet operational data
3.2. **CO₂ Simulation by Theoretically**

LPG is a fuel with a lower carbon content than gasoline. If the combustion process is assumed by complete combustion, where LPG and gasoline do not produce CO and HC emissions, then the amount of CO₂ produced per km can be known. Gasoline has a density of 0.75 kg/liter so that 1 liter of gasoline weighs 750 grams. Gasoline consists of 87% carbon, which means one liter consists of 652 grams of carbon. To burn all the carbon content into CO₂ takes 1740 grams of oxygen. The amount is 652 + 1740 = 2392 grams of CO₂/liter of gasoline. Meanwhile, the density of LPG is 0.55 which means 1 liter of LPG weighs 550 grams. LPG consists of 82.5% carbon or 454 grams of carbon per liter of LPG. To burn all the carbon content into CO₂ takes 1211 grams of oxygen. The amount is 454 + 1211 = 1665 gram CO₂/liter of LPG [14]. Tailpipe CO₂ with energy consumption of 13,311 MJ/km (≈1 liter gasoline) can be presented in Figure 4.

![Figure 4. Tailpipe CO₂ emission from gasoline and LPG](image)

With the energy content approach, Gasoline and LPG have a slightly different energy content (LHV) of 44.15 and 46.28 MJ/kg, respectively [15]. From the data available, 306 unit fleets serving 12 lines in Magelang City will require gasoline of 59,984 liters/year (44,449 kg/year) or equivalent to 1,986,237 MJ and then produce CO₂ of 143,626 kg (143.5 tons). The energy of 1,986,237 MJ is equivalent to 42,918 kg of LPG (78,032 liters) and then produce CO₂ of 129,924 kg (129.9 tons). From these calculations, there is a potential for CO₂ reduction of 9% or about 13.56 tons per year.

3.3. **CO₂ Simulation from NEDC Experiences**

From the literature study, there are many reports on the emission comparison of vehicles fueled by LPG and gasoline [16]–[20]. However, in this study, we will use data reported by Institut Francais du Petrole [21] because it uses the New European Driving Cycle (NEDC) with a variety of samples. Table 1 presents the emissions comparison of gasoline and LPG vehicle using NEDC.

| Emission | Gasoline (g/km) | LPG (g/km) |
|----------|----------------|------------|
| CO       | 1.03           | 1.094      |
| HC       | 0.075          | 0.061      |
| NOₓ      | 0.05           | 0.016      |
| CO₂      | 171.2          | 152.9      |
From the data presented in Table 1, it appears that differences in CO, HC, and NOx emissions are not significant, while CO$_2$ shows a significant difference. With existing vehicle data, the use of gasoline and LPG will produce CO$_2$ of 102.69 and 91.72 tons/year, respectively. From the experience of testing with NEDC, there is a chance of decreasing CO$_2$ by 11% or equivalent to 10.98 tons/year. A comparison of theoretical simulations and NEDC experiences is presented in Figure 5.

![Figure 5](image_url)

**Figure 5.** Estimation of CO$_2$ emissions from the public fleet in Magelang City by theoretical simulations and NEDC experiences

3.4. An alternative strategy for implementation

In recent years, owners and operators of public fleets have anxiety due to the presence of online transportation or Transportation on Demand (ToD) so that their income decreases. Therefore, the most rational conversion program from gasoline to LPG/Vi-Gas is implemented by the local government through a grant scheme or cooperation with the company through a CSR scheme. Since the fuel conversion program involves energy, environmental, supply and technological readiness, the local government can form a consortium with the Department of Transportation, the Environment Agency, Pertamina as a State-Owned Enterprise, a converter kits provider, and a university to conduct continuous research. In Magelang, efforts to reduce CO$_2$ from the transportation sector are an important issue to support city branding as a clean city and also to support tourism area connectivity.

4. Conclusion

Through this simulation study, we found that applying LPG/Vi-Gas to public fleets in Magelang is worth considering by Local Government in order to reduce CO$_2$ emissions. From theoretical calculations and comparing with NEDC experiences, there is a potential reduction of CO$_2$ by 13.6 and 11.0 tons per year, respectively. To realize the conversion program, a consortium financing scheme involving the Local Government, Department of Transportation, the Environment Agency, Pertamina as a State-Owned Enterprise, a converter kits provider, and a university to conduct continuous research is the most appropriate for the vehicle owner to receive benefits as soon as possible.

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