Hybrid electric vehicle power consumption analysis in tropical area

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Abstract. Internal Combustion Engine (ICE) is one of the biggest fossil fuel consumers. Many attempts have been made by researchers to replace ICE with electric motors and batteries as a source of energy. On the other hand, the dependence on ICE cannot be eliminated. One of the better ideas is to combine an ICE with an electric motor or called a hybrid. This study aims to determine the amount of energy consumption used by Hybrid Electric Vehicles (HEV) in urban areas in a tropical megapolitan city. The method used is to monitor the use of energy in hybrid cars directly. Sensors and data acquisition are installed on the vehicle to find out the route, speed, fuel consumption, electricity consumption, etc. Data acquisition is also placed on pure ICE vehicles with comparable engine capacity. Previous research, namely the analysis of energy consumption in the Plug-In Hybrid Electric Vehicle (PHEV), will also be used as a comparison. The results obtained indicate that HEV could travel 22 kilometers with one liter of gasoline. ICE car could cover 13 kilometers by 1 liter of petrol. And PHEV could travel 34 kilometers with 1 liter of gasoline. Thus it can be concluded that HEV has the advantage of saving gasoline usage, but PHEV is the best of them.

1. Introduction

Indonesia is a developing country with quite a large population of motor vehicles. In certain areas, such as Jakarta and its surrounding supporting cities, the number of motorized vehicles is the most congested, because Jakarta is still a center of concentration in economic activity, not only on Java but in Indonesia. According to statistical data in 2018, the number of gasoline four-wheeled vehicles in Jakarta is more than four million units[1]. As a consequence, of course, congestion and air pollution cannot be avoided[2].

In 2019, Jakarta was the city with the worst level of air pollution in the world. The most significant contributor to pollution is two-wheeled motor vehicles, buses, and four-wheeled vehicles[3]. Four-wheeled motor vehicles accounted for 16.11% of Jakarta's air pollution. In this percentage, there are substances such as PM, HC, CO, NOx, and Sox[4]. Then the 2020 data, quoted from IQAir [5], Jakarta
ranks ninth in the city with the highest air pollution in the world. It means that Indonesia is not yet out of the top 10 cities with the worst air quality.

The conversion of ICE vehicles into electric vehicles is one of the ideal solutions[6]. Of course, this requires time for preparing facilities, infrastructure, and mature regulation. This step needs to be bridged subtly, one of which is to use hybrid vehicles. The vehicle engine is a combination of ICE with an electric motor.

In Indonesia, hybrid vehicles are still classified as luxury and expensive vehicles. Two primary movers in a car also make the purchase taxes are high. Therefore, at present, hybrid cars can only be purchased by the upper-middle class. The purpose of the purchase was more prestigious. Apart from that, the movement to reduce air pollution must be started and encouraged. If demand and population increase, it is believed that the price of hybrid vehicles will decrease, especially if accompanied by supporting taxation policies[7].

2. Literature
Hybrid vehicles are vehicles that have more than one power source to drive. The most common examples are hybrid cars with ICE power and electricity, called the Hybrid Electric Vehicle (HEV). HEV energy is obtained from the battery. In HEV, the battery can only be charged while the car is driving. The charge process occurs when the function of an electric motor turns into an electric generator, i.e., during ICE work (Figure 1). Also, the charge occurs when there is a braking[8] or deceleration process. This charging process is called regenerative braking. Another type of HEV is PHEV[9]. PHEV has an additional feature where the battery can be charged from an outside power source[10].
In general, HEV is divided into three types. The first is the HEV series. In this type, ICE is only used to rotate the alternator. The alternator charges the battery. The battery is then used to drive the electric motor. When the battery capacity is insufficient, ICE will charge the battery. There is no direct mechanical connection between ICE and the vehicle transmission box.

The second type is the parallel HEV. In this type, both ICE and electric motors are connected to the transmission box. When the battery is sufficient, the electric motor will work. When the battery is inadequate, ICE will drive the vehicle while turning the electric motor. This rotation makes the electric motor function as a generator to charge the battery. Under certain conditions, where higher power or torque is needed[11][12], the algorithm will instruct the ICE and electric motor to work at the same time (parallel). In these conditions, the battery must be at a level that meets the requirements. Thus the parallel type is more potent than the serial HEV with the same capacity.

The third type is a combination of serial and parallel HEV. The characteristic of this type, ICE, is connected to the transmission box and a generator as well. This generator is connected to a power converter to drive the motor. The motor is connected to the transmission box.

In this study, the 2017 HEV Toyota Prius was used. This vehicle is a series-parallel HEV type, with a 134 bhp/100 kW output system of ICE. The HEV electric motor output is 80 bhp.

The Prius uses 168 NiMH (Nickel-metal hybride) batteries, where the voltage per cell is 1.2 V. The maximum battery voltage is 201.6 volts and 6.5 Ah (Table 1). Thus the energy capacity is 1310.4 Wh (1.3 kWh)[13].

Figure 1. Operation of HEV
Table 1. ICE and EV Toyota Prius 2017 specification

| HYBRID SYNERGY DRIVE |  |
|----------------------|---|
| Type                 | Series/parallel, full hybrid |
| System output (bhp/kW)| 134/100 |
| ENGINE              |  |
| Engine type          | 2ZR-FXE (Atkinson cycle) |
| No. of cylinders     | Four in-line |
| Valve mechanism      | 16-valve DOHC with VVT-i |
| Bore x stroke (mm)   | 80.5 x 88.3 |
| Displacement (cc)    | 1,798 |
| Compression ratio    | 13.0:1 |
| Fuel system          | EFI |
| Octane No.           | 95 or greater |
| Max. power (bhp/kW @ rpm) | 98/73 @ 5,200 |
| Max. torque (Nm @ rpm) | 142 @ 4,000 |
| Emissions level      | Euro 5 |
| ELECTRIC MOTOR       |  |
| Motor type           | Permanent magnet, synchronous |
| Max. voltage (CD V)  | 650 |
| Max. power (bhp)     | 80 |
| Max. torque (Nm)     | 207 |
| HIGH-VOLTAGE BATTERY |  |
| Battery type         | Nickel-metal hydride |
| Nominal voltage (SC V) | 201.6 (168 x 1.2V cells) |
| No. of battery modules | 28 |
| Battery capacity (Ah) | 6.5 |
| System voltage (V)   | 650 |

Source: https://media.toyota.co.uk/wp-content/files_mf/1329489972120216MTOYOTAPRIUSTECHNICALSPECIFICATIONS.pdf

The electrical energy capacity of 1.3 kWh can also be converted as 78 kW minutes. It means that if within 1 minute required 78 kW of power, the battery would run out within 1 minute, then ICE will work fully replace the electric motor. If the average energy needed to run a vehicle in EV mode is 15.6 kW, the battery is only able to drive an electric motor for 5 minutes. This is assuming that the battery can be discharged up to 0%. In fact, the battery has never been or is not allowed to reach 0%. At the point of 20-30% remaining capacity, the battery will be recharged[14].

3. Methodology/Experimental
In this study, conducted experimentally. HEV is installed with a tool for data acquisition that can record data on the use of fuel and electricity within a specific time. Besides that, the vehicle position data is also recorded while driving. Vehicles are used every day under normal conditions[15]. The study was conducted in areas of Jakarta, Bogor, Depok, Tangerang, Bekasi, with congested road conditions combined with toll roads. Because the average temperature in the tropics is quite hot, air conditioning is always used. Unlike the PHEV, in HEV, there is no selection of fully BEV or fully ICE modes. Thus there is only one mode, hybrid. AC on HEV is driven by a separate electric motor, in contrast to AC on ICE vehicles driven by crankshaft rotation.

The vehicle is driven according to driver behavior. The route taken is from home to work and back home. Thus it is expected to collect data on what is the average distance per day. From here, it can be developed to determine fuel consumption. The results of the analysis are used to conclude whether hybrid vehicles are significant enough to save fuel use, which indirectly shows a contribution to the reduction in air pollution levels (Figure 2).
This research will focus on HEV fuel consumption. Data obtained from the data logger will also be used for further study.

![Experiment flow chart](image)

**Figure 2.** Experiment flow chart

4. **Result and Discussion**

Data was taken from June 26 to September 28, or about three months. From Table 2, it can be seen that in the driving range between 0-10 km, fuel consumption was the most wasteful at 8.6 km/liter. The total distance in the range of 0-30 km was more than 200 km. The best fuel consumption in the range was 17.1 km/liter. Also, the data shows that more than 1200 minutes of the time needed for a range of 0-30 km. In the range of 30-60 km, the total distance of about 600 km and the whole travel time of about 2000 minutes. The best fuel consumption was in the range of 60-90 km, which was 23.1 km/liter.

For a range of 90-110 km, the total mileage was less than 320 km. The best fuel consumption was in the range of 100-110 km, which was 24.9 km/liter. The highest average speed was in the range of more than 110 km, which was 27.8 km/hr.

Mileage of more than 110 km gave average fuel consumption of 22.4 km/liter. The total cruising distance in this range was more than 2300 km.

From several groups the range can be seen, within three months, with everyday use, if the conditions of use were at a speed range of 0-10 km, fuel consumption was 8.6 km/liter. The best conditions were in the range of 100-110 km, which was 24.9 km/liter. The average fuel use during the experiment period (three months) was 21.95 km/liter, with a total mileage of more than 5600 km.

Behavior driving on this vehicle, the longest distance was in the range 70-80 km, 80-90 km, and more than 110 km. The miles of more than 110 km are classified as out-of-town trips because the Jabodetabek city range itself is between 30-40 km. Thus the round trip around 60-80 km. If the range of more than 110 km is ignored, then the longest distance was in the range of 70-80 km. It was 1266.6 km.
Table 2. HEV energy consumption – experiment data of Prius

| Range     | Trip Time [min] | Driving Distance [km] | Fuel Consumption [L] | Fuel Economy [km/L] | Average Speed [km/h] |
|-----------|-----------------|-----------------------|----------------------|---------------------|----------------------|
| 0-10 km   | 266.8           | 32.1                  | 3.7                  | 8.6                 | 7.23                 |
| 10-20 km  | 634.4           | 132.8                 | 7.8                  | 17.1                | 12.56                |
| 20-30 km  | 519.4           | 102.7                 | 6.0                  | 17.0                | 11.87                |
| 30-40 km  | 1119.5          | 281.0                 | 14.3                 | 19.7                | 15.06                |
| 40-50 km  | 302.7           | 92.2                  | 4.4                  | 20.8                | 18.28                |
| 50-60 km  | 624.0           | 224.4                 | 10.0                 | 22.3                | 21.58                |
| 60-70 km  | 445.5           | 138.3                 | 6.1                  | 22.6                | 18.63                |
| 70-80 km  | 3073.5          | 1266.6                | 54.8                 | 23.1                | 24.73                |
| 80-90 km  | 1897.2          | 689.7                 | 30.7                 | 22.4                | 21.81                |
| 90-100 km | 287.6           | 97.2                  | 4.4                  | 22.3                | 20.28                |
| 100-110 km| 571.6           | 214.4                 | 8.6                  | 24.9                | 22.51                |
| >110 km   | 5087.2          | 2356.9                | 105.4                | 22.4                | 27.80                |
| Overall   | 14829.2         | 5628.3                | 256.4                | 21.95               | 22.8                 |

In Figure 3 can be seen more simply. The tendency of fuel consumption will save between 50 to 110 km. After that, fuel efficiency cannot be increased anymore. Besides, Figure 3 also shows that in a range below 50 km, fuel efficiency is not very good.

![Figure 3. Fuel efficiency including weekend - HEV](image)

Referring to Table 3, which claims that the fuel consumption used ranges from 72.4-76.4 mpg, or about 25.6-27 km/liter, then these conditions approach the fuel efficiency of the experiment in the ranges of 70-80 km and 100-110 km, but it still below the claim value from Toyota.
Table 3. Prius HEV claim

| FUEL CONSUMPTION       | 15in wheel |
|------------------------|------------|
| Combined               | 72.4 70.6  |
| Extra urban (mpg)      | 76.4       |
| Urban (mpg)            | 72.4       |

Source: https://media.toyota.co.uk/wp-content/files_mf/1329489972120216MTOYOTAPRIUSTECHNICALSPECIFICATIONS.pdf

5. Conclusion and Suggestion

The results of experiments in dense tropical regions, illustrate that actual fuel consumption is higher than the claims of the brochure.

The air conditioning is mandatory in the tropics. It should be suspected that energy is also channeled large enough to cool the cabin. It is consistent with previous research, which states that AC is the second-largest power consumption after the main motor in tropical electric vehicles [2].

The use of HEV in big city areas with almost always traffic jams like Jakarta only gives a small added value to fuel savings.

The dominant driving distance of the driver in this experiment is between 70-80 km, and in this range also shows the most efficient fuel consumption. The range can be a reflection of the distance from home-office and offices every day and represents the distance from Bekasi - Jakarta, Bogor-Jakarta, and Tangerang-Jakarta.

For tropical areas and big cities like Jakarta, traffic conditions are not favorable. But if HEV is used to cover medium distances (70-80 km), the benefits will be optimal.

In subsequent studies, it is very strategic to discuss the relationship between HEV, PHEV, BEV prices, local fuel prices (Indonesia), taxation, and battery prices. The research is essential so that it can provide suggestions to policyholders, consumers, and producers related to the type and price of the best electric vehicles for developing countries. Greenhouse issues, scarcity and rising fuel prices, electricity unit prices, and the amount of tax will determine the acceptance of electric cars in Indonesia.

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References
[1] H. Widowati 2019 Berapa jumlah kendaraan di DKI Jakarta? databoks [Online]. Available: https://databoks.katadata.co.id/datapublish/2019/08/02/berapa-jumlah-kendaraan-di-dki-jakarta.
[2] H. C. Frey, X. Zheng, and J. Hu 2020 Variability in measured real-world operational energy use and emission rates of a plug-in hybrid electric vehicle Energies, 13, no. 5, 1140.
[3] D. H. Jayani 2019 Kualitas udara jakarta terburuk di dunia databoks [Online]. Available: https://databoks.katadata.co.id/datapublish/2019/07/29/kualitas-udara-jakarta-terburuk-di-dunia.
[4] R. Arifin 2019 Motor penyumbang polusi tertinggi DKI Jakarta oto detik [Online]. Available: https://oto.detik.com/berita/d-4668990/motor-penyumbang-polusi-tertinggi-dki-jakarta.
[5] Admin 2020 Air quality and pollution city ranking IQAir [Online]. Available: https://www.iqair.com/world-air-quality-ranking.
[6] G. Heryana, S. Prasetya, M. Adhitya, and D. A. Sumarsono 2018 Power consumption analysis on large-sized electric bus IOP Conf. Ser. Earth Environ. Sci. 105 12041.
[7] W. YS, C. KT, and C. CC 2006 Battery sizing for plug-in hybrid electric vehicles J. Asian Electr. Veh. 4, no. 2 899–904.
[8] R. Siregar, M. Adhitya, D. A. Sumarsono, G. Heryana, and F. Zainuri 2019 Study the brake
performance of a passenger car based on the temperature that occurs in each brake Unit 2–9.

[9] K. J. Holmes, E. Mantus, J. Kassakian, and E. Zeitler 2016 The plug-in electric vehicle system from technologies to consumers World Electr. Veh. J. 8, no. 4 721–732.

[10] G. Heryana et al. 2020 Plug in hybrid electric vehicle power consumption analysis in tropical area AIP Conf. Proc. 2230, no. 1 50001.

[11] Nazaruddin, M. Adhitya, D. A. Sumarsono, R. Siregar, and G. Heryana 2016 Review of electric power steering type column steering with booster motor and future research for EV-Bus AIP Conf. Proc. 2227, no. 1 20016.

[12] F. Zainuri, D. A. Sumarsono, M. Adhitya, and R. Siregar 2017 Design of synchronomesh mechanism to optimization manual transmission's electric vehicle AIP Conf. Proc. 1823.

[13] J. Thomas, S. Huff, B. West, and P. Chambon 2017 Fuel consumption sensitivity of conventional and hybrid electric light-duty gasoline vehicles to driving style SAE Int. J. Fuels Lubr. 10 no. 3 672–689.

[14] I. Cho and J. Lee 2020 Characteristics of battery soc according to drive output and battery capacity of parallel hybrid electric vehicle Appl. Sci. 10 no. 8 2833.

[15] Y. Zhou et al. 2016 An assessment of causes of PEV success across US Metro areas World Electr. Veh. J. 8 no. 4 818–830.