The role of waste compaction facility for reducing greenhouse gasses emission of waste transportation

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Abstract. Waste sector contributes on greenhouse gasses (GHGs) including from waste transportation. As it significantly contributes to the total cost, municipality is most concerned on waste transportation. The paper aims to analyze the role of waste compaction facility to reduce the GHGs emission reduction. Through a sampling procedure for 8 consecutively days, total waste collected from the service area to the compaction facility was 122.35 m$^3$ d$^{-1}$ with waste density of 103.27 kg m$^{-3}$. In order to transport all amount of waste to final disposal site located about 45 km from central of Bandung City, Indonesia it requires at least 8 trucks for 2 trips with waste density at truck of 200 kg m$^{-3}$. Waste compaction results the increasing waste density up to 350 kg m$^{-3}$. Thus, the truck required for waste transportation becomes 4 trucks. By assuming fuel efficiency of 5 km per litre of diesel and using emission factor published by DEFRA of UK (2.67 kg CO$_2$ eq. per litre), it is found that total GHG emission reduction due to operational of waste compaction is 40% (from 720.9 into 432.54 kg CO$_2$ eq. daily). In fact, the GHGs emission is reduced more when considering the traffic jam along way to final disposal site.

Keywords: greenhouse gasses, waste compaction, reduction, transportation

1. Introduction
Waste sector contributes on greenhouse gasses (GHG) including from waste transportation, treatment and disposal. In term of waste itself, GHGs emission from waste sector are divided into several categories which are: solid waste disposal, biological treatment process, thermal treatment process, and wastewater treatment [1]. In many countries, waste transportation becomes a big problem and many attempts were made to solve the problem [2][3][4][5].

Most municipality in Indonesia still adopts conventional waste management system that puts three main activities, collect, transfer, and disposal. As it significantly contributes to the total cost, municipality is most concern on waste transportation [6]. Various measure was taken to reduce the transportation cost including establishing waste compaction facility at transfer station site. The paper aims to analyze the role of waste compaction facility to reduce the GHGs emission. Compaction facility at Tegallega located at South part of Bandung City was taken as a case study.
2. Research Methods
In order to get amount of waste collected at transfer station, 8 consecutively-days of sampling were performed according to National Standard of SNI 19-3964-1995. Recording on quantity of waste compacted, frequency of waste compaction, number of transportation cycles to landfill, as well as specification of compaction machine were also conducted.

A simple calculation was done to find an average of waste quantity enters the transfer station and compaction machine. Reduction of GHGs emission was calculated by comparing transportation cycles if the compaction facility was not built at transfer station. There is no National Standard for emission factor to calculate the emission from transportation. Thus, in the study, GHGs emission from vehicle adopted standard of Department for Environment Food and Rural Affairs (DEFRA) of UK.

The analysis of this study will find the level of GHGs emission reduction due the operational of waste compaction facility at transfer station.

3. Result and Discussion

3.1. Waste generator and collection system
Waste generated at Tegalega transfer station was coming from South part of Bandung City, Indonesia (Regol sub district and Astana Anyar Sub district) which is distinguished into three main sources namely traditional market; residential area; and street sweeper. Waste generated at source was handled in different method. Waste from traditional market and street sweeper was collected daily using truck. While waste from residential area was collected every two days using handcart via door-to-door collection to transfer station site.

3.2. Waste generation, composition and characteristic
From 8 consecutively days sampling procedure, it can be found that total waste collected to the transfer station site was 122.35 m³ d⁻¹ as shown in Table 1. Various waste collection means enters to the site and dominantly by handcart which collected the waste mainly from residential area as shown in Table 2. Similar with other area in Indonesia, composition of municipal solid waste generated in the service area of Tegallega transfer station was dominated by organic waste (leftover food, garden waste), followed by plastic as shown in Figure 1.

| Day sampling | Volume (m³ d⁻¹) | Density (kg m⁻³) | Weight (ton d⁻¹) |
|--------------|----------------|-----------------|-----------------|
| 1            | 123.10         | 119.54          | 14.7            |
| 2            | 123.99         | 95.42           | 11.8            |
| 3            | 128.69         | 88.98           | 11.4            |
| 4            | 130.60         | 96.36           | 12.6            |
| 5            | 112.07         | 96.39           | 10.8            |
| 6            | 109.76         | 117.33          | 12.9            |
| 7            | 127.41         | 97.43           | 12.4            |
| 8            | 123.19         | 114.74          | 14.1            |
| Total        | 978.81         | 826.19          | 100.8           |
| Average      | 122.35         | 103.27          | 12.6            |

3.3. Waste handling system at transfer station
Scavenger occurred at transfer station plays important rule to reduce amount of waste. Small quantity of organic waste was composted at site. As compaction machine has a limited capacity some portion of total waste arrived at transfer station could not be compacted before it transported to final disposal. The rest of amount of waste was directly transported without compaction process. Schematic diagram
of waste reduction on volume basis covering different waste handling system can be found at Figure 2 below.

### Table 2. Amount of waste collection means enter to transfer station

| Means            | Day Sampling |
|------------------|--------------|
|                  | 1  | 2  | 3  | 4  | 5  | 6  | 7  | 8  |
| Handcart         | 53 | 52 | 47 | 69 | 57 | 70 | 68 | 60 |
| 3-wheels motorcycle | 6  | 5  | 6  | 6  | 5  | 9  | 10 | 11 |
| Small truck      | 2  | 1  | 0  | 2  | 0  | 1  | 2  | 1  |
| Single cabin car | 0  | 1  | 0  | 1  | 0  | 0  | 0  | 0  |
| Dump truck       | 1  | 1  | 4  | 2  | 1  | 2  | 2  | 1  |
| Box car          | 2  | 1  | 1  | 1  | 2  | 2  | 0  | 2  |
| Big box car      | 1  | 1  | 0  | 0  | 0  | 1  | 1  | 1  |
| Other            | 2  | 1  | 2  | 2  | 5  | 0  | 4  | 4  |

![Figure 1. Waste composition at transfer station](image1.png)

![Figure 2. Volume-based reduction before transported to final disposal site](image2.png)

3.4. **Waste handling system at transfer station**

Waste compaction reduces total volume of waste to be transported to final disposal. Table 3 represents simulation on number of truck and its cycles required if compaction machine was not available at transfer station site. Some assumptions were taken for the simulation:

- Volume of truck to transport the waste to final disposal site = 8 m³
- Frequency of transportation = 2 trips per day per truck
From the data, the effectiveness of the compaction process can be calculated. The effectiveness of compaction was represented by value of compaction factor. Compaction factor resulted from the field was 1:0.57. It means that 1 unit volume of waste enters the compaction machine produces 0.57 unit volume waste compacted.

Other parameter to analyze the performance is the increasing waste density after compaction process. In this case, waste compaction at Tegallega transfer station resulted the increasing waste density up to 350 kg m\(^{-3}\).

3.5. Cost Effectiveness

Further analysis was made in order to find cost effectiveness particularly for waste transportation from transfer station to final disposal site (Table 4). From transfer station, waste to be transported to Sarimukti final disposal site located at Cipatat Sub district, West Bandung Regency; about 45 km from Tegallega transfer station site. Some assumption below was made to find the cost effectiveness.

- Fuel consumption = 5 km per litre
- Price of fuel = IDR 5,150 per litre (0.412 USD per litre)
- Conversion: 1 USD = IDR 12,250

| Day- | Without Compaction | With Compaction | Saving (USD daily) |
|------|--------------------|-----------------|-------------------|
|      | Volume (m\(^3\))  | Trip (d\(^{-1}\)) Truck (unit) | Volume (m\(^3\)) | Trip (d\(^{-1}\)) Truck (unit) | Cost (USD daily) |
| 1    | 123.10            | 15               8 | 70.17            | 9               4 | 88 |
| 2    | 123.99            | 15               8 | 70.67            | 9               4 | 89 |
| 3    | 128.69            | 16               8 | 73.35            | 9               5 | 93 |
| 4    | 130.60            | 16               8 | 74.44            | 9               5 | 94 |
| 5    | 112.07            | 14               7 | 63.88            | 9               4 | 80 |
| 6    | 109.76            | 14               7 | 62.56            | 9               4 | 79 |
| 7    | 127.41            | 16               8 | 72.62            | 9               5 | 92 |
| 8    | 123.19            | 15               8 | 70.22            | 9               4 | 88 |
| Average | 122.35          | 15               8 | 69.74            | 9               4 | 88 |

As waste management is still public service provided by municipality, local municipality should responsible for the waste transportation. In order to cover the investment cost, central government
namely Ministry of Public Work takes the role. Thus, the existence of compaction machine will reduce significantly the waste transportation cost for local municipality.

3.6. Prediction of GHGs emission
Calculation of GHGs emission was based on guideline issued by Department for Environment Food and Rural Affairs, United Kingdom (2009) for freight transport operation. Fuel contains carbon which is released as carbon dioxide when burnt in an engine. In this study, GHGs emission was calculated based on fuel consumption required for waste transportation from transfer station to final disposal site.

However, as there are no direct records of fuel consumption, in this study the fuel usage obtained from vehicle distance travelled and vehicles efficiency (Figure 3). One trip of each truck travelled for 90 km from Tegallega transfer station to Cipatat final disposal site and back to central of Bandung City. By assuming fuel efficiency of 5 km per litre of diesel, one trip of truck will need 18 litres of diesel.

Diesel emissions factor are different for each different fuel, they may even vary from one country to another as different composition may be applied. Using emission factor of 2.67 kg CO$_2$ eq. per litre \[7\], GHGs emission for 18 litres of diesel equals to 48.06 kg CO$_2$ eq.

Reduction of GHGs emission due to the operational of compaction machine can be found by comparing total distance of waste transportation when the compaction machine was not operated. GHGs emission = Number of trip of total truck * fuel consumed * emissions factor

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\text{GHGs emission} = 15 \text{ trip} \times 18 \text{ litres per trip} \times 2.67 \text{ kg CO}_2 \text{ eq. per litre} = 720.9 \text{ kg CO}_2 \text{ eq.}
\]

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\text{GHGs emission} = 9 \text{ trip} \times 18 \text{ litres per trip} \times 2.67 \text{ kg CO}_2 \text{ eq. per litre} = 432.54 \text{ kg CO}_2 \text{ eq.}
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\text{Reduction of GHGs emission} = (720.9 - 432.54) \text{ kg CO}_2 \text{ eq.} = 288.36 \text{ kg CO}_2 \text{ eq.}
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It is found that total GHG emission reduction due to operational of waste compaction is 40% daily. So, if it is summed up for a year 105.25 ton CO$_2$ eq. will be prevented to emit. In fact, amount of GHGs emission is reduced more when considering the traffic jam along way to final disposal site.

![Figure 3. Fuel estimation flowchart [7]](image-url)
4. Conclusion
GHGs emission generated by waste sector will be proportional to amount of waste generated and transported. Reduction of transportation distance of waste to final disposal site could be obtained by installing compaction machine at transfer station site. In case of Tegallega transfer station, the compaction machine able to reduce 40% of GHGs emission. In other hand, the existance of compaction machine will also provide advantage in term of financial as number of truck required to transport to final disposal becomes less.

In general, implementation of 3R (Reduce Reuse Recycle) concept starting from waste generator will prevent much more GHGs to be emitted. Various method could be applied for better solid waste handling system, including composting, waste-bank, anaerobic digester, sanitary landfill etc.

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