Greenhouse gas emissions comparison of solid waste transportation system: a case study in Thailand

J Koiwanit\textsuperscript{1} and C Hamontree\textsuperscript{2}

Faculty of Engineering, King Mongkut’s Institute of Technology Ladkrabang, Bangkok 10520, Thailand
E-mail: Jarotwan.ko@kmitl.ac.th

Abstract. During the early periods of civilization, solid waste was conveniently collected transported and disposed because of the low number of population. However, waste generation is expected to increase because of rapid population growth and consequently shows an increase in solid waste collection, transportation, and disposal. Waste transportation planning is a difficult task due to the issues of the increasing numbers of garbage vehicles and the fluctuation of fuel prices as well as the cost-effectiveness and health and environmental impacts. An unsustainable waste collection and transportation is heading towards a variety of indirect human health impacts. Accordingly, the vehicle routing problem (VRP) plays a significant role in the field of waste collection and transportation system. This study compares three different Life Cycle Assessment (LCA) approaches for the waste transport in Ladkrabang, Bangkok, Thailand. The three scenarios are modelled using GaBi 7 software tool and results are presented based on the CML 2001. The assessment outcomes indicated that the routing optimization with diesel and electric garbage trucks could significantly reduce the GWP impact by 8.51\% and 66.44\% compared to the baseline scenario, respectively.

1. Introduction
Worldwide, the total costs of approximately 410\$ billion incurred in municipal solid waste management every year. Collection and transportation especially in developing countries comes to about 85\% of the total costs [1]. According to [2], the SWM collection process was approximately 74\% of the SWM cost but routing issues have not been much paid attention. In addition, transportation planning has direct impacts on people’s lives through changes in air quality concerns [3]. It is a negligible role of transports on the environmental impact of waste transportation. The routing optimization problem in the case of solid waste management collection has been explored with many algorithms, which have been developed for its optimal solution [4].

In this study, tool was introduced and its distance results were further analysed based on the LCA methodology. This study presents how LCA tool can be applied in the routing vehicles’ planning process of the waste transportation in Ladkrabang, Bangkok, Thailand. CML 2001, the life cycle inventory analysis (LCIA) method, is used to characterize GWP impact. This study is a gate-to-gate study focusing on the way how transport is organized [5]. This reliable waste transportation data is currently not available and this will provide an inclusive resource of informative evaluation of waste routing options [6].

2. Implementation of LCA methods
2.1 Goal and scope definition
The goal of this study is to study GWP environmental performance over the use phase of solid waste transportation systems and compare their environmental performance with a traditional solid waste transportation system. The GWP impact results are specific to solid waste transportation services in Ladkrabang, Bangkok, Thailand.

The main objectives of this study are:

- to improve our understanding of the emissions and energy consumption in the use phase of the garbage trucks;
- to examine the GWP impacts of different types of solid waste transportation systems;
- to encourage the use of an electric garbage truck to achieve the goal of CO₂ emissions reduction.

However, other factors, such as life-cycle investment cost, maintenance cost, replacement cost, etc., would not be taken into account in this study.

2.2 Functional unit
The functional unit for the study is selected from the same capacity in collecting solid waste though there are different in transportation routes and vehicle types. As a result, the functional unit selected in this study is a round trip of solid waste collection and transportation system.

2.3 System boundaries
This study is a gate-to-gate study that takes into account the solid waste transportation. Transportation of waste to waste treatment facilities is included in all scenarios. The garbage trucks with traditional routes consuming fossil fuel was used as a reference case. Production and usage of fossil fuel are included in the reference case system boundaries. The other two scenarios are the same in transportation routes and distances using genetic algorithm (GA) with the nearest neighbor heuristic but different in vehicle types, which include conventional vehicle and electric vehicles. Though the three scenarios are different in either transportation routes or vehicle type, there is the same amount of solid waste. Production and usage of electricity from battery are included in the electric truck system boundaries.

2.4 Temporal and geographical boundaries
The lifespan of the trucks in this study is assumed to be 12 years with an assumed lifetime driven distance of 230,500 kilometers [7-9]. However, vehicles will be able to operate more than their design lives [10].

2.5 Technological boundaries
There are three systems analyzed, which include: (i) the electric garbage truck with the new average distance results using genetic algorithm (GA) with the nearest neighbour heuristic, (ii) the conventional garbage truck with the new average distance results using genetic algorithm (GA) with the nearest, and (iii) the conventional garbage truck with the traditional route.

There are many methods offering fast running time and yielding near optimal solutions. One of the most natural heuristic methods is the nearest neighbour method [11]. This method is to always visit the nearest city and then return to the starting node (city) when any other cities are visited [12].

In terms of genetic algorithm (GA), this is an optimisation technique and heuristic search for the final solution based on nature search [13]. At the beginning of algorithm, a randomly generated initial population are created and a GA carries out the evaluated fitness function and recombination to produce an optimal answer. However, if we do not get the successor population, the next generation is produced with selected parent chromosomes based on their fitness and their genetic is recombined to produce the new children fitness. This process is repeated until it is reaching the best solution to a given problem [13, 14].

In this study, the GHG impacts from a battery electric vehicle (EV) in use phase were investigated and compared with its conventional garbage truck.
3. Life cycle inventory (LCI) analysis
In this study, the majority of the data used is specific to Thailand. However, some sources of data are from Ecoinvent, China, the U.S., and worldwide.

3.1 Description of conventional garbage truck
The garbage trucks will collect the waste everyday in the Ladkrabang area, shown in Figure 1.

![Figure 1. Ladkrabang area, Bangkok, Thailand [15].](image)

Based on the Google map, the travel distances each day before and after using genetic algorithm (GA) with the nearest neighbour heuristic is shown in Table 1. The energy use for the traditional garbage trucks is from the combustion of diesel.

| Day     | Traditional distance (km.) | New distance (km.) | Distance difference (km.) |
|---------|-----------------------------|--------------------|---------------------------|
| Monday  | 355.10                      | 301.95             | -53.15                    |
| Tuesday | 333.61                      | 306.11             | -27.50                    |
| Wednesday | 292.65                    | 290.45             | -2.20                     |
| Thursday | 353.79                      | 321.54             | -32.25                    |
| Friday  | 335.01                      | 300.36             | -34.65                    |
| Saturday | 315.55                      | 293.88             | -21.67                    |
| Sunday  | 357.74                      | 329.72             | -28.02                    |
| Total   | 2,343.45                    | 2,144.01           | -199.44                   |

Average per day 334.778571 306.287143 -28.491429

3.2 Description of electric garbage truck
Electric vehicles are becoming more important modes of green transportation because of its environmentally-friendly impacts. In this study, an electric garbage truck was chosen as a vehicle to
pick up waste from each station in Ladkrabang district, in Bangkok, Thailand. The trucks used in this study are the garbage truck as shown in Figure 2.

![Garbage trucks travelling through the city](www.bangkokbiznews.com)

**Figure 2.** Garbage trucks travelling through the city (www.bangkokbiznews.com).

There are three main parameters contributing to the EV’s energy consumption as follows [16-18]:
- The driving resistances that are required to put the vehicle into movement.
- The use of auxiliaries (e.g. ventilation, light, air conditioning, etc.).
- Energy losses for converting electric energy of the battery into mechanical energy for the wheels into movement.

Based on [15], the average weight of solid waste is assumed to be 34,905.83 kgs per day and the travel distance each day using genetic algorithm (GA) with the nearest neighbour heuristic. The operating parameters are shown in Table 2.

| Parameter                        | Value | Unit   | Reference/comment                |
|----------------------------------|-------|--------|----------------------------------|
| Driving behavior                 | -     | -      | Cautious                         |
| Type of road                     | -     | -      | City                             |
| Slope of the road                | -     | -      | Flat                             |
| Acceleration                     | 0     | m·s⁻²  |                                   |
| Total weight (kg) (vehicle and waste) | 44,411 | kgs    | [15]; www.okorder.com            |
| Average solid waste per round    | 34,905.83 | kgs    | [15]                             |
| Rolling friction of the tires    | 0.08  | -      | www.engineeringtoolbox.com       |
| Temperature at time of the travel| 35    | c      | Expert’s estimate                |
Density of air at 35 °C = 1.15 kg·m\(^{-3}\) (www.engineerstudent.co.uk)

Aerodynamic drag coefficient = 0.6 (www.part20.eu)

Frontal area of the vehicle = 2.48*3.25 m \(\times\) m (www.okorder.com)

Velocity = 25 m·s\(^{-1}\) (www.okorder.com)

4. Life Cycle Impact Assessment (LCIA)
This study takes into account all energy consumption and associated emissions during the use phase of the garbage trucks using CML2001 methodology and GWP is the main focus of this study. All components modeled using GaBi 7, a friendly user LCA software produced by PE International, Germany. The three scenarios were compared based on the GWP impact and the results were analyzed. The analysis of the results is presented below.

5. Global warming potential (GWP) results
In this study, the GWP is 536.16, 490.52, and 179.92 kg CO\(_2\)-Equiv. in the diesel truck with traditional waste collection routes, diesel truck and electric truck with new collection route using GA, respectively. In this study, the purposed routes with diesel and electric vehicles were compared to the existing routes and the results using LCA showed that the GHG environmental impact can be decreased up to 8.51% and 66.44%, respectively. Because of the longer distance of the waste collection system, the GWP impact was highest for the base case scenario compared to the diesel and electric trucks with purposed routes.

In addition, there was the least net total CO\(_2\) and GHG emissions in electric garbage truck system since its usage of electricity instead of fossil fuel which significantly helps lower energy output and CO\(_2\) emissions emitted into the air. The study showed that switching to electric vehicles eliminates the GHG emissions emitted into the air caused by fuel combustion. By promoting electric vehicle modes, this will at least help mitigate the air pollutants and eventually leads to zero emission fuels. The GWP of different vehicle types and routes of waste collection transportation services are shown in Figure 3.

![Figure 3. Global warming potential of different vehicle types and routes of waste collection transportation services.](image-url)
6. Conclusions
In our urbanizing world, sustainable waste management system particularly in transportation is considered as one of the most important issues. The environmental impact of collecting and transporting waste from individual households to disposal depends mainly on the vehicles operating parameters and the distance. The objective of this study is to compare and find out which of the two routes together with different vehicle types is more environmentally friendly. The results show that the new waste collection and transportation’s route would reduce distance and emissions and thus GWP impact each round. These assessment outcomes provide decision-makers with the potential of LCA as a rich source of capturing long-term effects of sustainable waste management planning strategies.

There are some weaknesses in this study in which there are many other processes which are not taken into account. These will result in different environmental impact. In addition, other environmental impact categories should also be taken into account. As a result, it is recommended for future work that this LCA study should be extended to include other processes as well as other environmental impact categories. Sensitivity analysis should also be taken into consideration.

7. References
[1] Ghose M, Dikshit A K and Sharma S 2006 Waste Manage
[2] Agha S R 2006 IUG J. Nat. Stu. 14 pp 75–89
[3] Eckelman M J 2013 Envi. Res. Letters 8(2)
[4] Karadimas N V, Doukas N, Kolokathi M and Defteraiou G 2008 Wseas trans. comput. 7(12) pp 2022–2031
[5] Girod C B and Marton S M 2014 Amer. Cen. for LCA. 446–472
[6] Miczah K, Obiri-Danso K, Kádár Z, Fei-Baffoe B and Mensah M Y 2015 Waste Manage. 46 pp 15–27
[7] Chen T D and Kockelman K M 2016 Transp. Res. D Transp. Environ. 47 pp 276–284
[8] Notter D A, Gauch M, Widmer R, Wager P, Stamp A, Zah R and Althaus H 2010 Environ. Sci. Technol. 44(17) pp 6550–6556
[9] Faria R, Marques P, Moura P, Freire F, Delgado J and Almeida A T 2013 Re. Sus. Ener. Rev. 24 pp 271–87
[10] Zackrisson M, Avellán L and Orlenius J 2010 J. Clean Prod. 18(15) pp 1519–1529
[11] Hougardy S and Wirko M 2015 Disc. Appl. Math. 195 pp 101–103
[12] Saiyed A R 2012 The traveling salesman problem.Terre Haute: Indiana. State. University, Terre Haute, USA.
[13] McCall J 2005 J. Comput. Appl. Math. 184(1) pp 205–222
[14] Zarei B, Meybodi M R and Abbasszadeh M 2007 In Proceeding of 6th IEEE/ACIS International Conference on Computer and Information Science, Melbourne, Australia
[15] Kongchom N and Tanyakorn S 2017 The study of suitable route for waste collection: a case study of Ladkrabang sub-district, Ladkrabang district, Bangkok. Bechaelor Thesis, KMITL.
[16] Küçükyay F 2014 In Proceeding of 11th Symposium: Hybrid & electric vehicles, Braunschweig, Germany
[17] Repmann C, Eilemann A, Pantow E, Wawzytnik M, Ayoubi M and Seiffert U 2013 Fahrzeugphysik. In H.-H. Braess (Hrsg.), Vieweg Handbuch Kraftfahrzeugtechnik, Wiesbaden: Springer Vieweg.
[18] Duce D A, Egede P, Ohlschlager G, Dettmer T, Althaus H, Büttler T T and Szczeczowicz E 2013 Guidelines for the LCA of electric vehicles. European Union Seventh Framework Programme.

Acknowledgements
We are grateful for the required information from Dr. Ronnapree Chaichaowararat for this project.