A Comparative of Life Cycle Assessment of a Conventional Van and a Battery Electric Van for an Online Shopping System in Thailand

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Abstract. The transportation sector is responsible for one of the main emitters of large quantities of pollutions to the atmosphere, which impacts local, regional or global environment receptors. In Thailand, many retail chains have been trying to launch many campaigns and projects to reduce GHG emissions together with offering the best convenience services to serve customers’ needs. By promoting an online shopping system for the workplace, this will mitigate even more of the air pollutants than the conventional online shopping system, where the products are delivered to customer’s doorsteps. This study aims to investigate and compare the impact of different vehicle technologies for an online shopping using Life Cycle Assessment (LCA) methodology especially in the vehicle use phase. The observed results showed that the electric van has the potential of reducing emissions and consequently showed lower impacts in most impact categories.

1. Introduction
In recent decades, climate change has had the strongest and most comprehensive impact to natural systems [1]. Greenhouse gas (GHG) emissions are known to contribute to the climate change and carbon dioxide (CO₂) is a major GHG [2]. In Thailand, transportation was ranged as the second largest contributor to CO₂ emissions [3]. Not only does road transportation contribute to the high costs of fuel consumption, but it will also lead to high GHG emissions and other environmental impacts. In 2015, there were approximately 39.3% of Thailand’s population using the internet and this results in an increase in online shopping system [4]. To cope with this issue, the use of an online shopping system has become an approach in ensuring lower emissions and thus alleviate traffic congestion. Furthermore, this consequently will benefit its users via lowered travel costs and time consuming [5]. However, instead of delivering products individually to each customer, retailers can deliver to workplaces at a certain time. Employees can take their groceries from their workplaces directly home instead of having to take individual trips to the grocery stores [6]. Previous research [6] has been done on evaluating and comparing the environmental impacts of the vehicle’s fuel consumption of the online shopping system with the traditional shopping system. In this study, the use phase of two types of vehicles, which include 1) battery electric vans and 2) conventional vans has been modelled to compare the life cycle impact using an LCA methodology.

As complexity of a product especially vehicles have a significant impact on the complexity of the LCA study, LCA on both conventional and battery electric vans (BEVs) are a challenging task. In recent decades, EVs using the LCA methodology have been studied [7]-[11], while [10], [12]-[15]
investigated electric vehicles (EVs) on specific components, especially Li-ion batteries. Most LCA studies focus on EVs production and their raw material acquisition, there is a few focusing on the use phase [16], [17]. In contrast to the previous LCA studies, this study attempts to model the use phase scenarios based on real life previous research data [6]. This study is a gate-to-gate study focusing mainly on culminating in the creation of a use phase database for conventional and battery electric vans on an online shopping system for workplace delivery at King Mongkut’s Institute of Technology Ladkrabang (KMITL) in Bangkok, Thailand. Center of Environmental Science of Leiden University (CML) 2001, the life cycle impact assessment (LCIA) method, is used to convert Life Cycle Inventory (LCI) data into 11 environmental impacts. This database is currently unavailable and few consider life-cycle impacts. As a result, this study will fill the gap and a useful database will be produced.

2. Implementation of LCA methods

2.1 Goal and scope definition
The goal of this LCA is to study environmental performance over the life cycle of an electric designed van compared to a conventional designed van. The main objectives of this study are:

- To have a complete understanding of the emissions, wastes, resource use and energy consumption in the use phase of the delivery vehicles.
- To improve our understanding of all related processes in road transportation for emission reductions.
- To encourage the increased use of an electric designed van as a solution for CO₂ emissions reduction for any retailer chains or logistic companies.

2.2 Functional unit
The most common way to compare the life cycle impact of one vehicle to another is to measure emissions per kilometer driven over their lifetimes. This is a common functional unit for comparing different forms of transportation that aims to carry a different number of passengers. Therefore, the functional unit selected in this comparative study is 1 km travelled. Even though running fuel is computed differently during on and off-peak times, this study assumed that the average electricity consumption rate is constant at any period of time.

2.3 System boundaries
This study is a gate-to-gate study that takes into account fuel type and fuel consumption through the vehicle use. The system boundaries of the electric and conventional designed van. The reference case (conventional van) system boundaries include production and usage of fossil fuel. The electric van system boundaries include production and usage of electricity from battery.

2.4 Temporal and geographical boundaries
In this study, a vehicle’s lifetime of 12 years and a lifetime driven distance of 230,500 kilometers were assumed. These number are the default expected life span values for a typical vehicle and car used in most research [9], [18], [19].

2.5 Technological boundaries
This study evaluates modern road-vehicle technologies and their emission impacts. There are two systems analyzed, which include: (i) the electric designed van intended for use in urban areas, and (ii) the conventional designed van.

3. Life cycle inventory analysis (LCI)
The majority of data are specific to Bangkok/Thailand. The assumptions about energy consumption and emissions emitted from the electric designed van are mainly derived from [6], [20], and Ecoinvent. Nevertheless, if there is still not enough data available to conduct the study of the use phase of the vehicles in Thailand, the data is taken from several literature reviews shown in Table 1.
Table 1. Main operating parameters of electric vans.

| Parameter                      | Value | Unit     | Reference/comment                  |
|--------------------------------|-------|----------|------------------------------------|
| Driving behavior               | -     | -        | Cautious                           |
| Type of road                   | -     | -        | City                               |
| Slope of the road              | -     | -        | Flat                               |
| Acceleration                   | 0     | m/s²     |                                    |
| Total weight (kg)              | 3500  | kg       | www.targetmovethailand.com         |
| Rolling friction of the tires  | 0.2   | -        | 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   | 0.38  |          | [21]                               |
| Frontal area of the vehicle    | 1.8 × 2.2 | m × m | Expert’s estimate                  |
| Velocity                       | 16.7  | m/s      | Expert’s estimate                  |
| **Energy consumption**         | **0.29** | kWh/km | Calculation based                 |

3.1. **Description of e-shopping system for workplace delivery using EVs**

Online shopping system in Thailand continues to increase because of the Thai consumer new lifestyles, high competition, and information technology. Many retailers launch their online shopping system at customers’ doorsteps but none have done the online shopping system for a workplace delivery to reduce more number of kilometres travelled, compared to a conventional online delivery system. In order to be environmentally friendly, different vehicle technologies can be considered. Electric vehicles (EVs) are one of the alternative options to reduce the amount of fossil fueled usage in today’s conventional vehicles. EVs also reduce noise and eliminate tailpipe emissions.

As the range of EV’s energy consumption depends on many parameters, it is variable. However, the energy consumption of EVs can be decided into 3 main aspects [7], [20], [22]:

- The driving resistances must be overcome to achieve and put the vehicle into movement.
- The use of auxiliaries such as light, air conditioning, radio, navigation, ventilation, etc.
- Energy losses in the process of converting electric energy of the battery into mechanical energy at the wheels of the vehicle.

In this study, in order to model delivery vehicles, a designed van was chosen as to drive their way from Srinakarin storage location to KMITL and driving resistances were taken into account.

3.2. **Description of e-shopping system for workplace using conventional delivery vans**

Based on the previous work [6], the conventional designed vans are based on Tesco Lotus’s vans in which there are 3 separate compartments. These compartments are for frozen (15 baskets), chilled (15 baskets) and non-perishable products (45 baskets) and this in total can carry 75 baskets per trip as shown in Figure 1.
Based on the interviews in the previous work, it can be concluded that each faculty member will get around one and half basket each week and most of them are non-perishable products. The study assumed that if all new members which are 23 buy products for 2 baskets each week, the designed van can deliver their products to the institute one time per week. The travel distance between the closet storage location and the institute is 34 km or 68 km in return. According to [23], the average is 22 mile per gallon which is equal to the fossil fuel usage at 0.107 liters per km.

4. Life Cycle Impact Assessment (LCIA)

Since this study aims to evaluate the overall environmental impact associated with each unit process of an electric designed van and a conventional designed van specific to Bangkok/Thailand, the accurate evaluation should be represented by the life cycle impact assessment methodology best suited for the Thai environment. This study employs CML 2001 since this method is well-established, comprehensive, and commonly used. In addition, GaBi 7, an LCA software product of PE International, Germany, is used in this study since this software is an easy-to-understand structure and friendly user interface.

5. Results

The two scenarios were compared based on these environmental impact categories and the results were analyzed. In terms of the electric vans, because no emissions emitted during the use stage, all contribution from any impact categories were derived from electricity generation. The percentage change (from the conventional van) in environmental impacts categories for the electric van is shown in Figure 2. The analysis of the results of LCA study is presented below.

5.1. Global Warming

The impact to the category of global warming was decreased by 57.39% in the electric designed van compared to the conventional designed van. The main reduction is mainly derived from using electricity instead of fossil fuel. The main substances that contributed to the global warming category include CO₂, methane (CH₄), and nitrous oxide (N₂O), which accounted for 95.1%, 2.48, and 1.08%, respectively. In the “conventional vehicle” scenario, around 83% of the contribution was derived from the car using stage and only 17% from gasoline mix at refinery.

5.2. Abiotic Depletion (ADP elements)

The results showed the impact to abiotic depletion considering ADP elements in the electric designed van is 7.83E-08 kg Sb-Equiv., which is a 32.5% increase for the electric designed van system. The main substances that caused this abiotic depletion impact category include Copper (Cu), silver, and Lead (Pb) which accounted for 24.3%, 21%, and 18.2%, respectively of the impact in this category. The increased impact of abiotic depletion (ADP elements) is mainly due to the electricity needed for operation of the vehicle system. In the “conventional van” scenario, gasoline mix contributed 100% to this impact category.
5.3. **Abiotic Depletion (ADP fossil)**
A total number in the environmental impact category of abiotic depletion considering ADP fossil is 1.73 MJ in the electric van system. The results showed that the impact to the abiotic depletion (ADP fossil) is reduced by approximately 66.4% for the electric designed van system compared to the baseline scenario. The gasoline mix for the conventional van and the electricity generation system are the primary sources for abiotic depletion. The dominant contributors to the abiotic depletion were lignite and hard coal, which accounted for 47.3% and 33.3%, of the contribution in this impact category, respectively. In the “conventional van” scenario, gasoline mix contributed 100% to this impact category.

5.4. **Acidification Potential (AP)**
The results showed that the total impact of the electric designed van system is 2.52E-04 kg SO$_2$-Equiv. and this has better performance compared to the conventional system. The impact to the acidification potential of the electric designed van scenario is reduced by 96.3% compared to the baseline scenario. The main substances contributing to the acidification potential impact category are hydrogen sulphide (H$_2$S), ammonia (NH$_3$), and hydrogen chloride (HCl), which accounted for 79%, 25.9%, and 24.9%, respectively. In the “baseline” scenario, around 53.2% of the contribution was from vehicle using stage and 46.8% was from operation of the gasoline.

5.5. **Eutrophication Potential (EP)**
The results showed that the total impact to the eutrophication potential is 4.01E-05 kg Phosphate-Equiv. The impact is decreased by 97.9% for the electric designed van system compared to the baseline scenario. The impact is mainly due to less amount of NO$_x$ and N$_2$O emissions emitted into the air, which accounted for 57.2% and 4.84%, respectively. In the “baseline” scenario, the vehicle using stage and gasoline mix contributed 52.9% and 47.1% respectively to the impact in the acidification category.

5.6. **Freshwater Aquatic Ecotoxicity Potential (FAETP)**
In the electric designed van scenario, the impact to the freshwater aquatic ecotoxicity is decreased by 93.3% mainly due to heavy metals emitted into the fresh water. The total impact was 2.34E-04 kg DCB-Equiv. The main substances that contributed to the freshwater aquatic ecotoxicity were Nickel (Ni) and Vanadium (V), which accounted for 40.6% and 22.2%, respectively. In the “baseline” scenario, 97% of the contribution was derived from vehicle using stage and 3.04% from the gasoline mix at refinery.

5.7. **Human Toxicity Potential (HTP)**
The electric designed van system shows the total impact in human toxicity potential which is 5.82E-03 kg DCB-Equiv. The total impact is reduced by 98.7 % compared to the baseline scenario. It was observed that the heavy metals (e.g. As, Cd, Cu, VOCs), and different inorganic emissions (e.g. hydrogen fluoride (HF) and NO$_x$) are emitted to atmosphere. In the “capture” scenario, 59.3% of the contribution was derived from vehicle using stage and 40.7% from the operation of gasoline mix.

5.8. **Marine Aquatic Ecotoxicity Potential (MAETP)**
The online shopping system using the electric designed van showed a total marine aquatic ecotoxicity potential impact of 19.9 kg Ethene-Equiv. Compared to the baseline scenario, the potential for marine aquatic ecotoxicity in the electric vehicle scenario increases by 235.2%. Electricity generating system of the electric van contributed 100% to the marine aquatic ecotoxicity impact category. HF from electricity generating station for the electric designed van accounted for 98.1% of the contribution in this impact category. In the “baseline” scenario, almost 100% of the eutrophication potential was derived from vehicle using stage.
5.9. **Ozone Depletion (ODP)**

Compared to the conventional designed van system, the results showed the impact to ozone depletion is increased by 205.02% for electric vehicle system. The total result of this impact category is 1.05E-11 kg R11-Equiv. The increased impact of ozone depletion is mainly due to the higher impact on electricity generation system compared to the operation of the gasoline. The dominant contributors to this impact category were dichlorotetrafluoroethane (R114) and dichlorodifluoromethane (R12) and, which accounted for 97.8% and 0.01%, respectively. In the “baseline” scenario, gasoline mix contributed 100% to this impact category.

5.10. **Photochemical Ozone Creation Potential (POCP)**

The results from the CML 2001 method indicated that the total impact of the photochemical ozone creation impact category is 1.88E-05 kg Ethene-Equiv. Compared to the conventional vehicle system, the impact is reduced by 102.9% for the electric vehicle system. The decreased impact is attributed to the less amount of emissions emitted into the air from electricity generation system compared to gasoline mix. The main substances that caused photochemical ozone creation include dichlorotetrafluoroethane (R114) and chlorodifluoromethane (R22) which accounted for 97.8% and 2.97%, respectively of the impact in this category. In the “baseline” scenario, the photochemical ozone creation impact was due to gasoline mix at refinery and vehicle using stage, which accounted for 54.4% and 45.6% of the impact, respectively.

5.11. **Terrestrial Ecotoxicity Potential (TEP)**

The results showed that the total potential for terrestrial ecotoxicity in the electric van system is 1.31E-04 kg DCB-Equiv. The impact to this impact category is increased by around 101% for the electric van system compared to the baseline scenario. The impact is derived from the trace elements collected from the electricity generation system. Heavy metals, which include mercury (Hg), chromium (Cr), As were the main substances that contributed to terrestrial ecotoxicity, which accounted for 78.5%, 5.31%, 3.36%, respectively. In the “baseline” scenario, the processes of vehicle usage and gasoline mix contributed 81.4% and 18.6% respectively to the impact on the terrestrial ecotoxicity impact category.

![Percentage change in impact categories](image)

**Figure 2.** Percentage change in impact categories for electric vehicle scenario.
6. Conclusions
Over a decade, e-commerce has seen significant growth in a new and more efficient era as the changing lifestyles of today’s shoppers. Together with undergoing changes to be more environmentally friendly, retailers have been launching many campaigns and project to reduce GHG emissions. Electric cars can be one of the alternative ways to help boost business by building retailers’ “green” image. The objective of this study was to examine the environmental effects of an electric designed van compared to a conventional van. An electric vehicle has become an increasingly more attractive option by reducing or eliminating the downsides of using a conventional fossil fueled vehicle. In big cities such as Bangkok, which suffer from severe air pollution, the use of electric vehicles is very valuable. This study recognizes gate-to-grate impacts of alternative modes of vehicles. Results suggest that the reductions in concentrations of CO₂ and other emissions accounted for the benefits in the environment impact categories of GWP, ADP elements, ADP fossil, AP, EP, FAETP, HTP, and POCP. This shows that the electric van contributes to a reduction in a number of emissions compared to the today’s designed vans, which means that using electric van was significantly better than using a designed van, especially in the use stage. In this study, percentages are used rather than absolute quantities; consequently, the impact categories, particularly marine aquatic ecotoxicity, appear to see significant increases. In addition, there are some weaknesses in the current version of the LCA analysis in which there are many other processes (e.g. parts production, transportation of parts production, end-of-life products), which are not taken into account. These will definitely result in different environmental impacts. It is recommended for future work that this LCA study should be extended to include other processes.

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