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Life Cycle Analysis of Lead Acid Battery used in Electric Vehicles (3 Wheeler) in Bangladesh

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ABSTRACT
Lead acid batteries have been rapidly used in electric vehicles (3 wheeler) in Bangladesh with typical environmental problems such as consumption of resources and heavy metal pollution. Thus to conduct a comprehensive analysis of the environmental impact of the battery to reduce environmental pollution is urgent. In this paper a life cycle analysis conducted by SimaPro software is applied to analyze and compare the environmental impact of lead acid battery (LAB) within the system boundary of "cradle-to gate". The results showed that the overall impact of LAB production on environment is the smallest. The key substances that causes the environmental impact of LAB is production stage (12.56 %) & use stage of (85.56 %) the batteries. This research work will provide a quantitative assessments of the environmental impact of battery which will be very important to take necessary prevention measures during disposals. This can obviously create scopes of further research in this area.

Keywords: Lead acid battery (LAB), Electric vehicle, Life cycle analysis (LCA), SimaPro 8.5, Environmental impact

1. Introduction
Mass-production of battery electric vehicles were introduced to the global market to reduce transport-related oil dependency, carbon dioxide (CO_2) emissions, and urban air pollution [1]. Thus the three wheeler electric vehicles (Easy bikes) have made a major leap in the last few years in Bangladesh [2]. As a result, lead-acid battery (LAB) industry has stimulated the rapid growth of Bangladesh's for more than a decade. Easy-bikes are now plying on road with parking number given from city corporations, municipalities and union councils.

Electric bikes uses lead-acid batteries as the power source, which emit lead into the environment through its production, uses and recycling process. These batteries thus contaminates soil, air and water with their toxic substances, posing long-term negative impacts on the environment and human health [3].

The lead acid battery contains 70% lead (lead and lead oxide), 20% sulfuric acid and 10% plastic materials. In recycling process batteries are broken, cover of batteries is removed and acid is drained out on adjacent land. Top portion is hammered for shredding of plastic and the lead posts fixed in the top are released [4]. Open pit smelting is done at high temperature to recover lead from lead oxide, which is known as smelting. Smelting process requires small amount of coal to facilitate the reaction of lead burning. During this process lead dust and toxic gases released which pollutes the environment.

In order to find the negative impact of these batteries used in electric vehicles, a life cycle assessment (LCA) of lead-acid battery has been performed to explore the environmental aspects of the battery production, use and recycling process. Life cycle assessment is a technique to analyze and evaluate resources and environmental impacts associated with all the stages of a product's life including raw material, production process, packaging, energy and some other human activity, including the collection of raw material, production, transportation, consumption, final disposal [5]. At present, LCA has been widely used in different areas.

The LCA conducted with a listing of the available technologies for lead-acid battery in the SimaPro software tool. This can obviously create scopes of further research on this area.

2. Lead Acid Battery
Lead acid batteries are the cheapest way to store energy. The construction of lead acid battery has two electrode one is lead (Pb) and other is lead oxide (PbO_2). These two electrodes are immersed in the solution of water and sulfuric acid (H_2SO_4). When battery is generating energy, the lead combines with the sulphuric acid to create lead sulphate ($PbSO_4$), and the lead oxide combines with hydrogen and sulphuric acid to create lead sulphate and water (H_2O) [5]. As the battery is getting discharged lead sulfate build up on the electrode and the water build up in the sulfuric acid solution. When the battery is charged the process reversed and lead sulfate combine with water to build lead and lead oxide on the electrode.
Charging: $2PbSO_4 + 2H_2O \rightarrow PbO_2 + Pb + H_2SO_4$
Discharging: $PbO_2 + Pb + H_2SO_4 \rightarrow 2PbSO_4 + 2H_2O$

There are two types of lead acid batteries based on their construction method- flooded and sealed. In flooded lead acid battery the electrode is immersed in electrolyte and regular refilling of water is required for proper working. While in sealed lead acid battery the electrolyte is immobilized.

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3. Methodology

Environmental impact assessment of LAB is carried out following the LCA procedure and Eco-indicator 99 (H) (SimaPro 8.5) model analysis is performed. The environmental impact categories are selected according to model analysis. The processes and substances are identified according to overall environmental impact. The structure framework of this paper is shown in Fig.1.

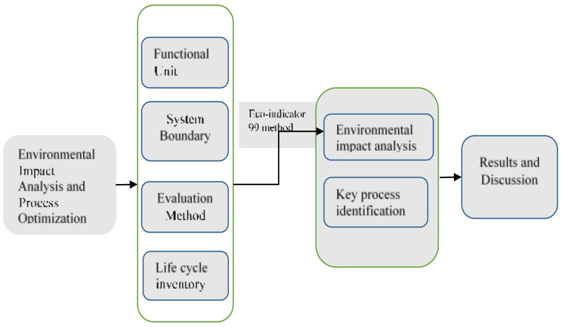

Fig.1 Structure framework of LCA

3.1 Functional Unit

All the raw material input, energy consumption, waste gas and waste water emission in the battery production process are calculated on the basis of the functional unit.

3.2 System Boundary

The battery system boundary is set to "cradle-to-gate" in Fig.2. It considers the battery production stage and the obtain stage of raw materials with the battery use stage and waste disposal stage. The system boundary of battery does not involve the problems of product quality allocation. Due to different types of raw materials used in the battery production process, the modes of transport are numerous. Therefore, the environment impact of raw materials transport is not taken into account.

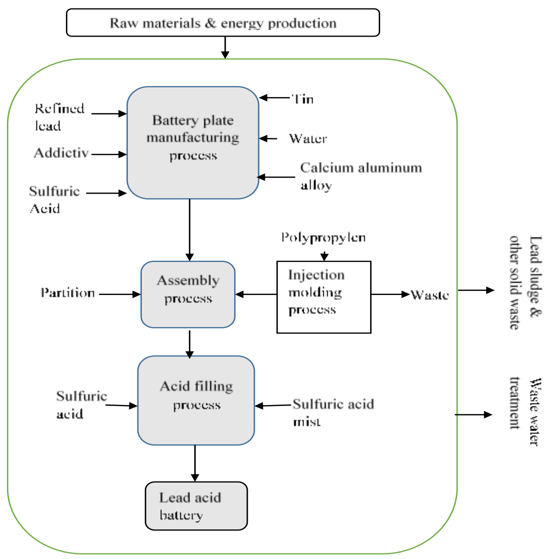

Fig. 2 System boundary of Batteries for LCA

3.3 Evaluation method

This study uses Eco-indicator 99 (H) model for life cycle impact assessment (LCIA) to perform all analyses. The Eco-indicator 99 model is the most widely used model in LCA and the most reliable intermediate point impact assessment method [6, 7]. The accuracy of the output results can be ensured from the data acquisition and model selection. The Eco-indicator 99 is one of the most widely used and the most reliable environmental impact assessment models in the world. It includes 18 midpoint environmental impact categories, i.e. climate change, ozone depletion, human toxicity, photochemical oxidant formation, particulate matter formation, ionizing radiation, terrestrial acidification, freshwater eutrophication, marine eutrophication, terrestrial ecotoxicity, freshwater ecotoxicity, marine ecotoxicity, agricultural land occupation, urban land occupation, natural land transformation, water depletion, metal depletion and fossil depletion [8].

3.4 Life cycle inventory construction

The focus of this LCA study is to evaluate the environmental performance of the lead-acid battery. The LCI data is basically a function of the quantity and type of energy consumed to operate the batteries. To quantify the data on amount of energy consumed, it is necessary to know the battery characteristic data and the application specific input data [9].

4 Stages of LCA

The lifecycle of a LAB can be divided into three main stages: production, use and disposal.

4.1 Production stage

Data related to energy consumption, input of raw materials and waste water and gas emissions of LAB is from a local battery manufacturer. Based on the literature reviews [10], this paper assumes that the number of LAB cycle is 350. LAB production process life cycle is shown in Table 1.

Table 1 Life cycle inventory (LCI) of lead acid battery (LAB) production process

Category	Name	1 kWh battery production	Unit	Data Sources
Battery plate manufacturing process	Refined lead	10.98	kg	Field survey
	Additive	0.16	kg	Field survey
	Calcium aluminum alloy	7×10^{-3}	kg	Field survey
	Tin	3.9×10^{-2}	kg	Field survey
	Deionized water	3.17	kg	Field survey
	Sulfuric acid	0.64	kg	Field survey
Process of Assembly	Partition	1.68	kg	Field survey

Acid filling process	Sulfuric acid	4.16	kg	Field survey
Injection molding process	Polypropylene	1.73	kg	Field survey
Energy consumption	Electricity	7.96	kWh	Field survey
	Steam	3.14	kg	Field survey

4. 2 Use Stage

Firstly, the use of battery & use of package was determined. In the use phase a battery needed to charge & change the electrolyte. Then, the data for type of energy consumed, i.e., the electricity generation (power grid) mix and life cycle environmental impacts associated with it was obtained from Ecoinvent 2.2 database. The type of electricity used to charge and discharge the batteries plays a significant role in the overall inventory of battery LCA studies. As the focus of the study is the Bangladesh distribution grid, the Bangladesh national electricity mix at distribution grid level was assumed in the analysis. LAB use stage is shown in Table 2.

Table 2 Energy and material inputs for Lead-Acid Battery use phase

Products	Materials/Assemblies/Process	Quantity	Unit
Use of A Battery	Distilled Water Production	1	P
	Electricity, medium voltage {BD}| market for electricity, medium voltage | APOS, U	2.8	kWh
	Municipal Waste		

4.3 Disposal phase

The disposal stage comprises the processes that products go through after their use is completed and are not providing the service for which they were devised. Whether due to malfunctioning or substitution, every product comes to a point when it has to be disposed of. A description hereafter of some possible ways to dispose of an end-life of Battery [11].

Data concerning the recycling processes is estimated based on an assumption regarding how much environmental burden can be avoided in total. Since the cell consists mainly of electrolyte (46%) and sealing gasket (15%), both assumed to be incinerated, only 20% of the total cell weight will be recycled as material (polypropylene). The environmental impacts of lead-acid battery recycling are calculated as the sum of environmental impacts from the transportation and involved recycling processes and treatment processes. LAB disposal stage is shown in Table 2.

Table 3 Energy and material inputs for Lead-Acid Battery disposal

Products	Materials/Assemblies/Process	Quantity	Unit
Disposal of Battery	Lead Acid Battery Assembly	1	P
	Transport, light commercial truck, diesel powered/tkm/RNA	0.2	tkm
	Transport, combination truck, short-haul, diesel powered/tkm/RNA	0.2	tkm
	Municipal Waste	50%	
	Disassembly of Battery	49%	
	Reuse of Container & Vent Plug	1%	

5 Life cycle analysis of a Lead-Acid Battery:

Total life cycle of a battery means the total view of production, use, and disposal. In a LC of Battery, for its charging it requires electricity. Also for its proper functioning it requires to change its electrolyte. For disposal state, it is considered that battery plates & other plastic component are recycled. Battery plates are go through the smelting process which facilitates the air emission. For the context of Bangladesh, the entire lifecycle of battery has negative impact. Fig. 4 shows the tree of Battery Life Cycle, Fig. 5 represents the Classification/ Characterization of the LCA, Normalization/ Weighing step on Fig. 7, Damage assessment step on Fig. 8 and finally the total contribution of each life stage to the total lifecycle aggregated in the main impact categories, Fig. 9 and Table 4.

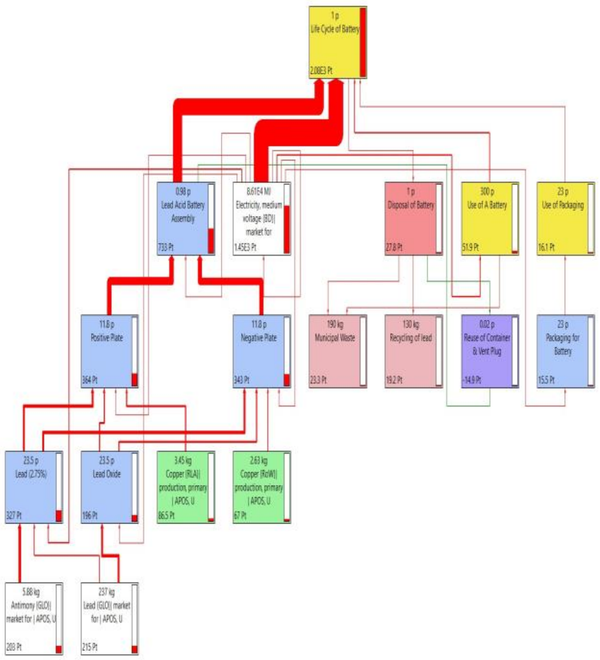

Fig. 3 Battery LCA network tree with a 5% cut-off

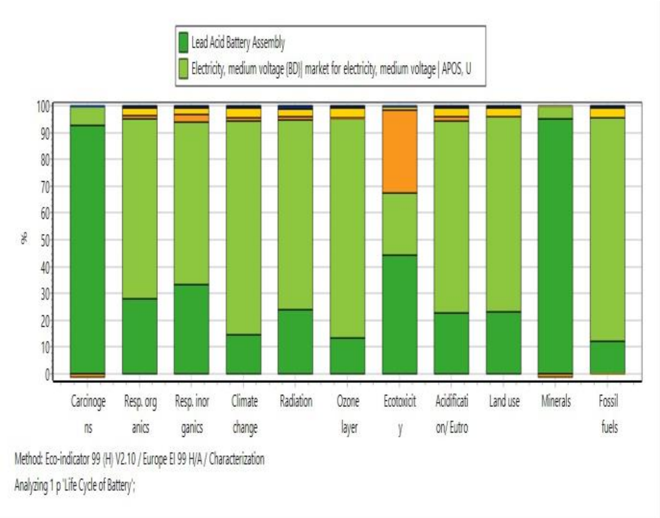

Fig. 4 LCA of a battery - Characterization Step

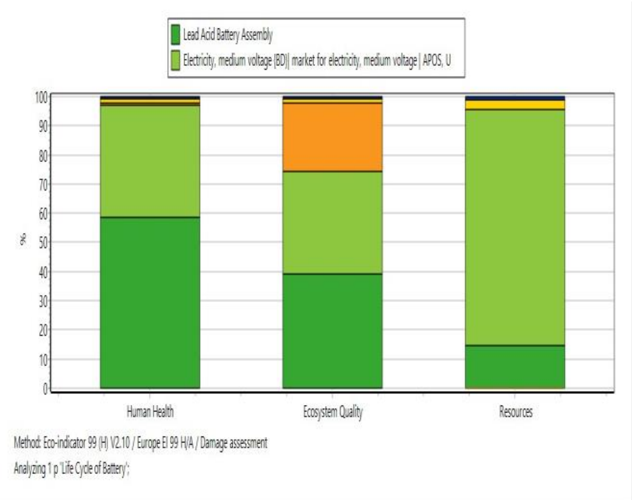

Fig. 5 LCA of a battery – Damage Assessment

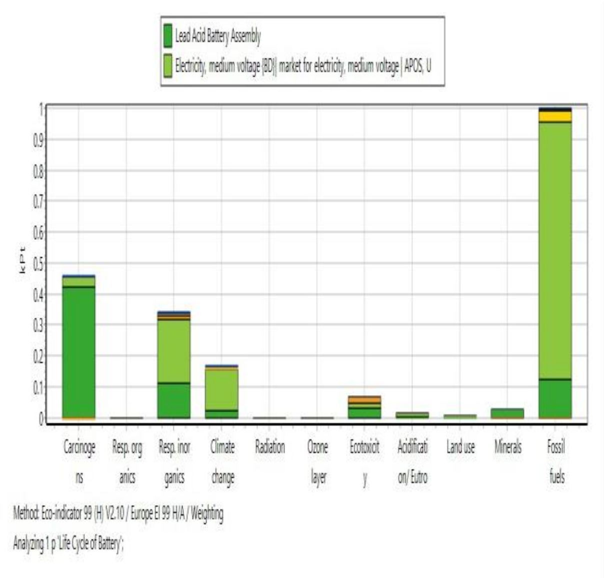

Fig. 6 LCA of a battery – Weighing Step

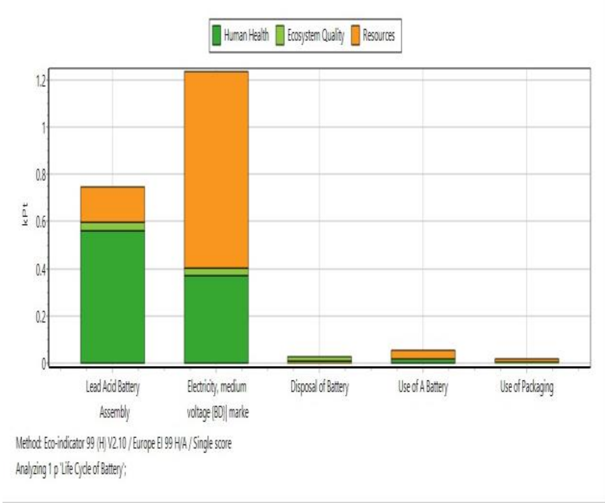

Fig. 7 LCA of a battery – Single Score

Table 4 Values of the contribution of each life stage in the total lifecycle of one battery

Damage category	Human Health	Ecosystem Quality	Resources	Total (kPt)
Lead Acid Battery Assembly	0.561	0.036	0.151	0.151
Electricity	0.370	0.032	0.833	0.833
Disposal of Battery	0.007	0.022	0.000	0.000
Use of A Battery	0.016	0.001	0.035	0.035
Use of Packaging	0.005	0.001	0.010	0.010
Total	0.959 (34 %)	0.092 (3.72 %)	1.028 (62 %)	2.079 (100 %)

6 Results

The previous figures and tables present the lifecycle ecopoints of the battery which amount to 2.097 kPt, where:

a. The production accounts for 0.151 kPt, i.e. 70% of the total impact;

b. The Electricity is responsible for 0.833 Pt, or 25% of the total environmental impact;

The categories with the highest contribution for the total lifecycle impact is Resources with a 62.27% input, followed by Human Health with 34%, Ecosystem Quality has a small contribution of 3.72%. In terms of the intermediary indicators, Fossil fuel have the highest impact in this parameter.

Using Eco-indicator 99 model, use stage is identified as the key process with the greatest impact on the environment (Fig. 7), which occupies 85.56% of the overall environmental impact load. In the 5 main environmental impact categories, the battery manufacturing process proportion of the environmental impact load 12.56 % (Fig. 7).

7 Conclusions

With the help of LCA, the environmental impact of LAB in the stage of "cradle-to-gate" is analyzed and compared. The processes and the substances of environmental impact were identified by the Eco-indicator 99 method. The results show that LAB use phase has the greatest environmental impact. These findings are important references for achieving sustainable development in the Electric vehicle using phase in Bangladesh.

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