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Research Article

Evaluating the Environmental Impact of a Bicycle: A Life Cycle Assessment with a New Green Product Design Framework

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ARTICLE INFO	ABSTRACT

The goal of this study is to assess the environmental consequences of bicycles manufactured in Bangladesh using a newly established framework for designing eco-friendly products. It is widely believed that pedal-cycles are environmentally benign and have high fuel efficiency. Increasing their use could help to reduce traffic congestion and carbon emissions. The study utilizes the ISO 14044 guideline and takes into account the entire life cycle of the bicycle, using life cycle inventory data acquired from a previously published article (Papon R et al., 2019). The findings of validating the suggested GDP framework were compared to the output of the life cycle assessment approach as presented in the paper by Papon et al. (2019). The study's findings indicate that manufacturing has the most significant environmental impact. Furthermore, the suggested GDP framework aligns well with this methodology. This study contributes to our comprehension of the impact of bicycles on the environment and presents an innovative Gross Domestic Product (GDP) framework for evaluating the environmental sustainability of other products.

Keywords: Life cycle assessment, Bicycle, Green Product Design(GPD), Framework, Environmental impact.

I.Introduction:

Background and Motivation

As all of us know, it is very difficult to arrange for space required for parking and operation of numerous vehicles. In addition, the heavy traffic necessitates the use of a lot of fuel, which is extravagant (Dresselhaus & Thomas, 2001). Thus, a high volume of movement of vehicles results in significant fuel consumption, air pollution, and financial damage (Van Mierlo et al., 2004). Furthermore, Pedal-cycles are the one best option to reduce congestion in cities in this regard and it is also preferable to use pedal-cycle to reduce traffic congestion in residential areas (Gámez-García et al., 2019). There is currently a lot of attentiveness is happening in pedal cycling, and manufacturers are also having tendency to release more attractive variants that use new and improved materials (Ahmad S, 2018). For short trips, bicycles are an effective form of transportation. In the last few years, both pedal cycles and E-bicycles have gained popularity and become more globally obtainable, making them an advantageous mode of transit (Monitor, 2018). The pedal-cycle market is currently growing at a rate of more than 100% year by year (Velosuisse, 2019). In the United States, 132 million bicycles are manufactured each year, with a total market value of 6.1 billion USD (S Brain, 2018). Furthermore, the international pedal-cycle market is expected to be worth 34.9 billion USD by 2022 (Rizwan et al., 2017). Mountain bicycles redord for 24% of all pedal-cycle sales, with hybrid bicycles accounting for 21% and street bicycles accounting for 20% (NBDA, 2020). Worldwide, Bangladesh is recognised as a leading producer of bicycles. The nation is the second-largest non-EU exporter of bicycles to the EU and the eighth largest overall (Rizwan et al., 2017). The export market for Bangladesh has started to grow as well as the country's bicycle industry.

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Objectives of this research are:
To evaluate the bicycle's environmental impact produced in Bangladesh.
To identify the stage in the life cycle of a bicycle that causes the maximum environmental burden.
To propose a novel green product design (GPD) framework for conducting life cycle assessment (LCA) of bicycles.
To validate the proposed framework by comparing its results with a previously published LCA study.
To contribute the understanding of the environmental impact of bicycles and to suggest the proposed new GPD framework as a useful tool for evaluating the environmental sustainability of other products.

II. Literature Review

The life cycle assessment (LCA) method assesses the environmental effects of all phases of a product's life, including the extraction of raw materials, the processing of those materials, manufacturing, distribution, use, repair and maintenance, and disposal or recycling (Finkbeiner et al., 2010). The life cycle, which is also referred to as a "cradle-to-grave" assessment, also takes into account the transportation consumption required for raw material extraction, production, and distribution (Kloepffer, 2008).

The practice of LCA is governed by the ISO 14040 series standards, namely ISO 14044:2006 and 2014. There are typically two types of life cycle assessments (LCAs) that are often used: multiple-figure LCAs and single-figure score LCAs, such as the suggested framework. Multi-figure life cycle assessment (LCA) measures the environmental impacts of a product in different categories. When comparing two or more product systems, calculations are performed for each of these numerous effect categories. This approach can be laborious, expensive, and puzzling, surpassing the ability of the majority of experienced designers.

Carbon fibre bicycles have the least negative environmental effects, while bicycles made of aluminium have the most negative effects (Margarida C. Coelho and Diogo Almeida, 2015). Christopher R. Cherry (Cherry et al., 2015) "analyzed the environmental impacts for different modes of transport, pointing on the energy consumption, generation of waste, and emissions corresponding with pedal-cycles ". Bicycles have fewer impact on the environment because they use fewer materials in production (Kbah, Z., et al, 2020). The effects on environment due to production of E-bicycle and its utilization in China were also examined (Cherry et al., 2015). According to bamboo bicycle frames life cycle assessment manufactured in Ghana, bamboo frame bicycles have a 50% lower environmental impact than aluminium frames and a 30% lower environmental impact than steel frames (Agyekum E O et al., 2017).

In the late 1980s and early 1990s, "green product design (GPD)" became increasingly popular due to a growing awareness of environmental issues such as material scarcity, high energy consumption, rising atmospheric CO2 levels, the ozone depletion of the atmosphere, the explosion of population, the decline of natural resources, and so forth (Toktas-Palut, P., et al, 2022). "Sustainable" was defined for the first time at the 1994 Oslo Roundtable (Aerais, 2010). Since then, numerous GPD definitions have been offered, as have examples of how it has been used in various fields.

Vinodh and Rajanayagam (2010) claim that a green production system's primary goal is to reduce environmental impact by fusing the effects of product and process design with process planning and control in order to recognize, gauge, assess, and manage the flow of environmental waste. Customers, stakeholders, and companies can benefit from green product design's economic and social benefits while also reversing environmental degradation in a practical and effective manner (Fuller and Ottman, 2004). GPD also incorporates eco-design practise, which focuses on striking a balance between environmental concerns and design goals with a business focus (Karlsson and Luttropp, 2006). According to Howarth and Hadfield (2006), the selection of "environmentally friendly" raw materials should be an organization's or a designer's top priority, after that best process for manufacturing and specifications during the phase of use and after that end life of the finished product with the least negative effects on society and the environment. GPD is widely marketed as a strategy that can offer significant advantages in the current global environment. As a result, numerous researchers have contributed to the growth and exploration of uncharted regions of the GPD field in order to advance the field of GPD research.

III.Methodology

In this study, the LCA of bicycle production in Bangladesh was conducted using ISO14040. This section discusses goal and scope of the proposed novel GPD framework's, life-cycle inventory, and life-cycle effect assessment method. Also discussed are the study's presumptions and the sources of the inventory data. The ISO standard states that an LCA study entails the following four steps: definition of the objective and scope, compilation of the life-cycle inventory, life-cycle assessment, and interpretation of the results (ISO 2006).

The scope, functional unit, and system boundaries must all be explicitly established at the outset during the life cycle assessment. The next step is to compile an inventory of the materials and energy utilized during each phase of the life cycle. The impact assessment is then completed using this data to calculate various environmental effects, which is the potential for global warming.

To achieve the goal of this study, the following steps have been followed:

a. Information Collection From previous publication for collection of life cycle inventories.
b. Define and use of Proposed GPD Framework for life cycle assessment of bicycle.
c. Data Validation and analysis

Information Collection From previous publication

- The Bangladesh bicycle industry agreed to provide information and interviews, so these were the sources for the bicycle-related data used in this study (Papon R et al., 2019).
- Furthermore, The largest producer and exporter of bicycles in Bangladesh, this industry accounts for the majority of this sector. It has 12 interconnected depot and 3 manufacturing stations for mass production of pedal-cycles (Group M, 2018).
- The authority had data on the parts and production of the reference bicycle. Inventory data for bicycle production were gathered through questionnaires and interviews (Papon R et al., 2019).
- The reference bicycle's weight was precisely measured for all of its parts and components. To calculate the transportation distance, secondary sources were used.
- Additionally, secondary data were gathered from a variety of literature sources, such as reports, online resources, earlier published articles, and Ecoinvent 3.5 (Ecoinvent, 2018).

Figure 1 shows the system boundary of the Bangladeshi bicycle industry's LCA study (Papon R, et al., 2019). The Eco Invent 3.4 database was used to obtain baseline data for the processing of raw materials (such as metal, rubber, plastic, and other materials) as well as raw materials from the environment, including inputs from the Technosphere, needed for the manufacture of bicycles (Ecoinvent, 2018).

Tables 1 and 2 demonstrate the material specifications for bicycle production in Bangladesh, as well as the components needed during use for entire life cycle, respectively.

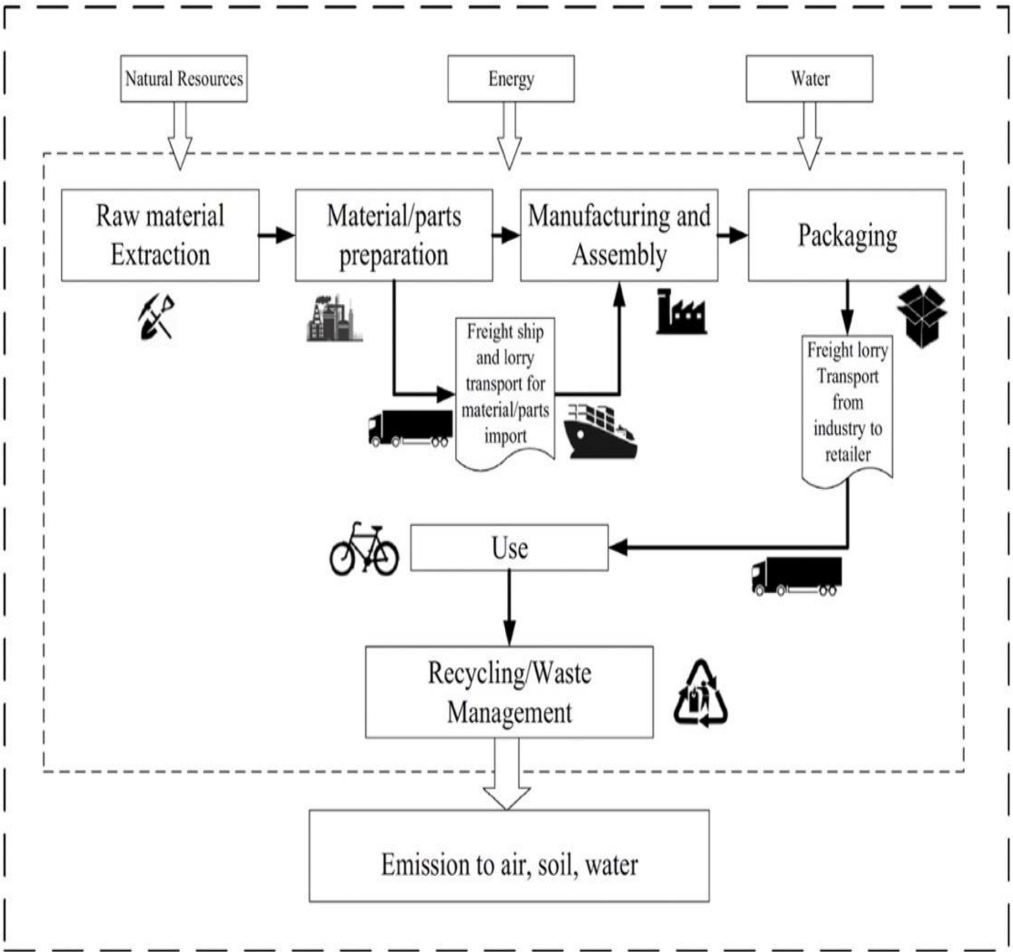

Fig. 1: System boundary of Bangladesh's bicycle industry's LCA study (Papon R, et al., 2019).

Table1: Life Cycle Inventory for bicycle production in Bangladesh (Papon R, et al., 2019).

Inputs	value	unit	output	value	unit
Aluminum alloyed	6.49	kg	Municipal solid waste	4.48	kg
Stainless steel	1.2	kg	Wastewater	7.1	m3
Steel alloyed	3.7	kg			
Wire	0.4	kg			
Plastic (Nylon)	1.5	kg			
PU, flexible foam	0.03	kg			
Rubber	1.4	kg			
Powder coat aluminum	0.21	kg			
Injection molding	0.98	kg			
Section bar extrusion, Al	2.5	kg			
Welding arc, Al	0.72	m			
Electricity	10.2	kWh			
Natural gas	0.325	m^3			
Tap water	0.71	kg			
Corrugated board	1.2	kg			
Packaging plastic	0.25	kg			
Packaging film	0.15	kg			

Al = Aluminum; kg = kilogram; m = meter; kWh = kilowatt-hour

Table 1: Parts needed to keep a bicycle in good condition over the course of its lifetime (Papon R, et al., 2019).

Elements	Quantity
Tire	4
Chain	1
Brake pads	6
Cassette	1

Proposed GPD Framework

The intended framework is a design-oriented framework that offers LCA factors with single-figure scores, which are significantly more efficient and user-friendly than those with multiple categories. This simplicity of use enables the framework to be implemented with nothing more than a pencil and paper. This method acquaints designers with the data to an extent that informs their design work substantially.

This proposed GDP framework used similar approach which is used by Philip White (White et al., 2013), which were created with modifications to the TRACI (Tool for Reduction and Assessment of Chemicals and Other Environmental Impacts) impact characterization method that was developed by scientists at the US Environmental Protection Agency (EPA). The factors combine ten environmental impact categories in one single-figure score.

This framework divide product life cycle into three stages (manufacturing, use and end of life) as shown in figure 2, which provide carbon emission value at every stage of product life cycle, lower the value greener the product.

The environmental effectiveness of a design concept can be evaluated in a variety of ways utilizing the GPD framework, which ranges from a swift preliminary assessment to a comprehensive examination of the entire product system. A multitude of methodologies may offer benefits, contingent upon the specific conditions and inquiries that the designer endeavors to resolve. Although conducting an exhaustive system life cycle assessment (LCA) is the main objective of employing this framework, it can also be utilized for basic screening and subassembly comparison.

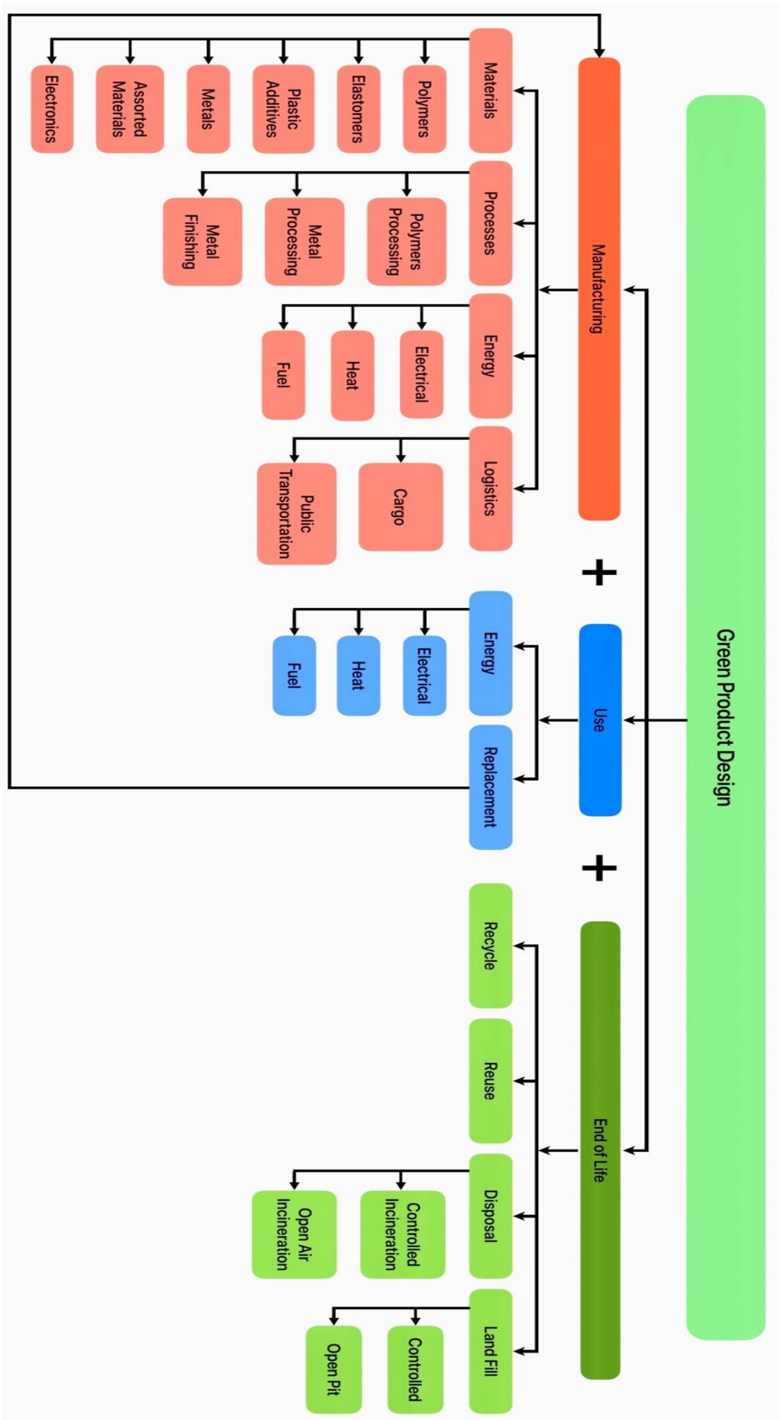

Fig 2: Proposed Framework GPD

The following steps are involved during the life cycle assessment of the product:
Step1: Define lifetime, function unit and system boundaries.
Step2: Make bill-of-materials
Step3: Calculation of estimated impacts

Data Validation and Analysis

It is assumed that a bicycle has an average lifespan of 15,000 kilo meters and number of tire replacements every 4000 km. During the lifetime of a padal-cycle there must be a replacement of four tyres, one chain, six brake pads (two wheels), and one cassette (Papon R, et al., 2019).

The average distance taken between industry and domestic pedal-cycle retailer shop was assumed to be 100 km by 18-wheelers (16 tonne). Furthermore, the footprint of pedal-cycle parts imported from Japan, Taiwan, and China was considered. Since, these parts were carried by sea (ocean freighter) from the correspondent country to Bangladesh, and then, all these parts were transported by 18-wheeler 16-ton truck up to industry, that was estimated to be a 250-km travel distance (Papon R, et al., 2019).

1. Define lifetime, function unit and system boundaries.

Bicycle

Lifetime	15,000 km
Functional Unit	Impacts/life
System boundary	Excludes cleaning during use

It is assumed that after use, bicycle metals and plastic will be disposed of in a controlled landfill.

2. Make bill-of-materials

		value	unit
Materials	Corrugated board	1.2	kg
	Packaging plastic	0.25	kg
	Packaging film	0.15	kg
	Aluminum alloyed	6.49	kg
	Stainless steel	1.2	kg
	Steel alloyed	3.7	kg
	S.Steel Wire	0.4	kg
	Plastic	1.5	kg
	PU, flexible foam	0.03	kg
	Rubber	1.4	kg
Manufacturing	Powder coat aluminum	0.21	kg
	Injection molding	0.98	kg
	Section bar extrusion, Al	2.5	kg
	Welding arc, Al	0.72	m
	Electricity usage	10.2	kWh
	Natural Gas	0.325	m^3
	Tap water	0.71	kg
Use*	Tire (rubber + S.S wire)	0.44 (each)	kg
	Chain (S. Steel)	0.28	kg
	Brakepad (rubber + Steel alloy)	0.29 (each)	kg
	Cassette (steel alloyed)	0.34	kg
Transport	Transportation by road	6440	kg.km
Disposal	landfill		

*Replacement during use (4 tiers, 1 Chain, 6 brake pads and 1 cassette).

3. Calculations:

Input	Amount	x	CO_2 eq *(kg)*	=	Value *(kg)*
Corrugated board	1.2 kg		0.44		0.53
Packaging plastic	0.25 kg		1.68		0.42
Packaging film	0.15 kg		1.22		0.18
Aluminum alloyed	6.49 kg		2.63		17.07
Stainless steel	1.2 kg		2.04		2.45
Steel alloyed	3.7 kg		0.907		3.36
S.Steel Wire	0.4 kg		2.04		0.82
Plastic	1.5 kg		4.218		6.33
PU, flexible foam	0.03 kg		4.8		0.14
Rubber	1.4 kg		1.77		2.48
Powder coat aluminum	0.21 kg		0.34		0.07
Injection molding	0.98 kg		0.59		0.58
Section bar extrusion, Al	2.5 kg		0.45		1.12
Welding arc, Al	0.72 kg		0.059		0.04
Electricity usage	10.2 kwh		1.18		12.04

Natural Gas	0.325 m³	0.01	0.003
Tap water	0.71 kg	0.019	0.013
Transportation by road	644 kg.km	0.19	122.36
During Use			
Rubber	2.61 kg	1.77	4.62
S. Steel wire	1.6 kg	2.04	3.26
S. Steel	0.28 kg	2.04	0.57
Steel alloyed	1.38 kg	0.907	1.25
Controlled landfill			
Corrugated board	1.2 kg	0.54	0.65
Packaging plastic	0.25 kg	0.045	0.011
Packaging film	0.15 kg	0.05	0.007
Aluminum alloyed	6.49 kg	0.006	0.039
Stainless steel	1.48 kg	0.006	0.009
Steel alloyed	5.08 kg	0.006	0.03
S.Steel Wire	2 kg	0.006	0.012
Plastic	1.5 kg	0.29	0.43
PU, flexible foam	0.03 kg	0.04	0.0012
Rubber	4.01 kg	0.09	0.36

Total impact/life of bicycle: 181.26 kg CO_2 eq

The process's precision is restricted to two significant integers. Consequently, the impacts are calculated on a per-functional-unit basis, with the outcome rounded to two significant digits.

Figure 3 shows the impact on environment of bicycle which is produced in Bangladesh during the three main life cycle stages of bicycle. It is a graphical representation of proposed GPD framework.

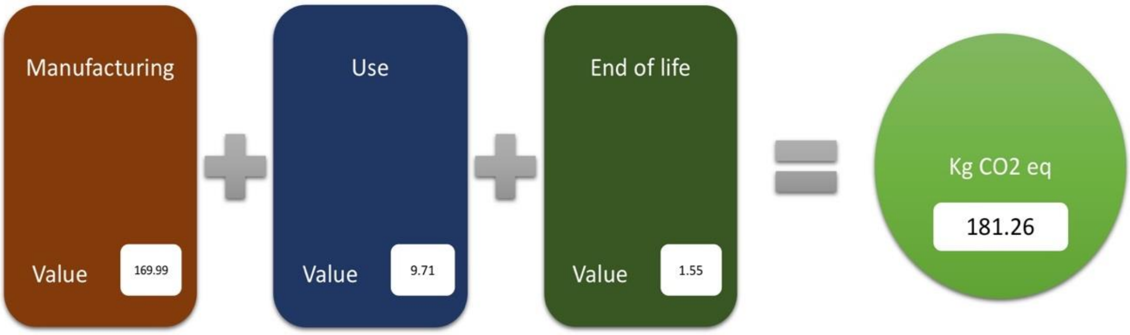

Fig 3: Environmental impact of bicycle at different stages

IV.Results and discussion

The traits of bicycles manufactured in Bangladesh are compiled in Table 3. The outcome was determined using the GPD framework, and it was then compared to the outcome of an article that had already been released which used the ReCiPe impact assessment technique to determine the outcome.

It is evident from the results that the manufacturing phase has the greatest environmental impact; energy consumption and the use of various metals, including aluminum, steel, and steel alloy, that are utilized in the production of pedal-cycles are proportionally high during this phase, resulting in a significant environmental impact. In contrast, as shown in Table 3, the use or maintenance phase has the second-highest environmental impact throughout the life cycle of pedal-cycle production in Bangladesh.

Table 3: Environmental impact of bicycle at different stages.

Stages	**Kg CO_2 Eq**
Manufacturing	168.87
Packaging	1.13
During use (for 15,000km life)	9.71
At the end of life	1.55

Figures 4(a) and 4(b) shows a comparison between the result of the proposed GPD framework and a previously published article,which depict the relative impact category contributions of various life cycle stages of a single pedal-cycle in Bangladesh.

Fig 4(a): Result from proposed framework

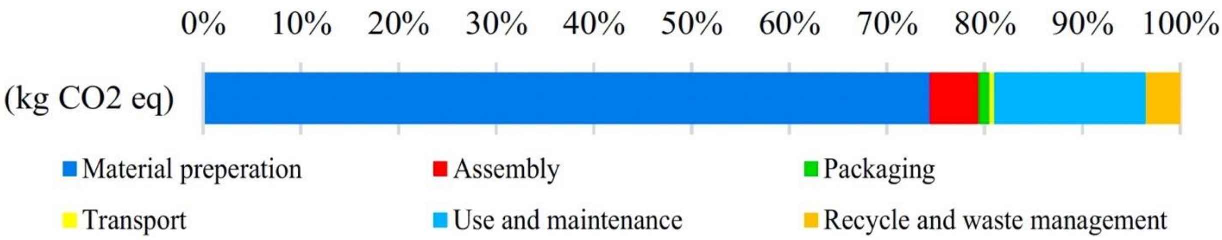

Fig 4(b): Result from published article (Papon R, et al., 2019).

V.Conclusion

By comparing the life cycle assessment of bicycles manufactured in Bangladesh, this research validates the new proposed life cycle assessment GPD framework with the existing approach. The manufacturing phases of each technique were discovered to have the greatest contribution to the environmental effect, followed by the use phase. As a result, this research confirmed that the findings of the new GDP framework are comparable to those of the published one. Furthermore, packaging and end-of-life stages were discovered to have negligible effects. This research has some limitations that should be acknowledged. Furthermore, there was no direct access to manufacturers, and there was no knowledge about supply chain entities or transportation of components from suppliers to final assembly. This research can be improved by involving manufacturers. The study's findings can help with the design of sustainable consumer goods. It has been demonstrated that even motorcycles have environmental consequences. Careful material selection, optimal component design, and energy use can all contribute to a reduction in the life-cycle impacts of bicycle production.
The study's findings indicate that bicycle manufacturing in Bangladesh has a high potential for lowering environmental risks. This research will contribute to the identification and maintenance of optimal bicycle manufacturing and management practices. Collaboration among industries is imperative to ensure pure manufacturing practices and the sustainable utilization of natural resources.

VI. Acknowledgment

Permission for use of Data from published article is already taken from the author of the published article. (Figure 1: Life cycle boundary of bicycle and Table 1: LCI of bicycle)

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