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Abstract: The surge in global CO_2 emissions resulting from extensive fossil fuel consumption has heightened concerns about global warming. As a response, there has been a significant shift towards eco-friendly energy sources, focusing attention on battery-operated vehicles. Bangladesh has witnessed the emergence of the *easy-bike*, a battery-operated three-wheeler public transportation mode. However, the introduction of these vehicles has raised environmental and societal concerns due to inadequate recycling of certain components. This study evaluates the life cycle sustainability of the easy-bike through the lens of the triple-bottom-line (TBL) framework, to promote circular economic development. Data collected from drivers, owners, and manufacturers underwent TBL analysis, yielding valuable insights. The study highlights the importance of circularity for sustainable progress, advocating for a comprehensive life cycle perspective across all aspects of sustainability to ensure accurate and reliable outcomes.

Keywords: life cycle sustainability assessment; triple-bottom-line; TBL; circular economy; emerging economy; electric vehicle; Bangladesh.

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1 Introduction

1.1 Context of research

The concept of circular economy (CE), representing a feasible departure from the conventional linear economic model of use-and-dispose, has garnered increasing attention within the discourse on environmental sustainability (Ungerman and Dědková, 2020; Hanumante et al., 2019). CE, a shorthand for recycling and reusing resources, primarily aims to reduce resource consumption by enhancing efficiency and minimising waste (Rossi et al., 2020; EMF, 2015). While the influence of local governance on sustainability endeavours has been extensively studied, limited attention has been paid to establishing connections between sustainable urban development and circular urban realms (Fratini et al., 2019). Implementing CE involves several key steps, including understanding circular principles, charting transition pathways, defining overarching goals, selecting relevant metrics (Ardra and Barua, 2022), developing practical methodologies aligned with regulatory standards, providing support for stakeholders, and actively engaging and communicating with diverse participants (Paiho et al., 2020). This study specifically delves into the emerging realm of battery-operated vehicle ventures recently integrated into Bangladesh's public transportation network. Swiftly after its inception, this mode of transportation garnered remarkable popularity, notably among urban denizens from low-income, lower-middle-income, and even middle-income strata. The sector evinces substantial potential for establishing self-sustaining enterprises and unlocking opportunities within diverse global markets. Local entrepreneurs and industrial entities within the region ardently advocate for the advancement of battery-powered vehicle technologies.

Due to its considerable expertise and skilled workforce, this sector is positioned to become a significant exporter of vehicular products in the future. The industry's growth trajectory and establishment of a corporate framework have raised the enticing prospect of exporting these vehicles to markets like India and the Middle East (Hizaamu, 2015). Leveraging the region's technological capabilities and resources, the nation has the potential to assume a pioneering role in electric vehicle manufacturing and related ventures. Regional dynamics exert a notable influence on the industry, leading to potential variations among suppliers. However, it is unlikely that such variations will persist in the long run, particularly within the energy sector, as suggested previously. Conversely, the Bangladeshi government asserts that battery-powered vehicles require a daily consumption of at least 300 megawatts of electricity for recharging, prompting measures to limit their deployment in urban areas. Despite this, the vehicle's growing popularity has the potential to stimulate local economic development. This paper provides insightful scrutiny into the industry's profound impact on CE dynamics within Bangladesh. Additionally, a comprehensive assessment of the battery vehicle's product life cycle will be undertaken to evaluate its integration within the CE paradigm.

Battery-powered tricycles, commonly referred to as *easy-bikes*, have emerged as a new fixture in Bangladesh's urban transportation network. Since their introduction, this mode of transport has gained wide popularity, particularly among urban residents from lower to middle-income brackets, owing to its cost-effectiveness and passenger comfort (Das, 2022). The development and establishment of its organisational framework have paved the way for potential vehicle exports to markets like India and the Middle East (Hizaamu, 2015). Leveraging its expertise and skilled workforce, the sector is poised to carve a niche for itself in the global business landscape. With the country's existing technological and resource infrastructure, it is well-positioned to play a leading role in the electric vehicle manufacturing domain, with the easy-bike as a prominent example (Plötz et al., 2017). Traditional motor vehicles have long been recognised as the primary contributors to air pollution, responsible for over 70% of total emissions in urban areas (Bull and Zimmann, 1997). The shift from diesel and petroleum-based vehicles to plug-in hybrid electric vehicles (PHEVs) holds the potential to significantly reduce pollution levels (Babar et al., 2021). The primary aim of this research is to conduct a comprehensive life cycle assessment (LCA), encompassing environmental, social, and cost evaluations within the vehicle industry. This initiative aims to provide a comprehensive understanding of the industry's impacts and dynamics across various dimensions.

1.2 Sustainability as a concept and practice

The sustainability paradigm proposed by Elkington (1998) serves as a foundational framework employed to outline sustainability parameters for industries or products. Academia and industry professionals are increasingly immersing themselves in sustainability concepts, highlighting their crucial role for local governments in fostering a green economy (Murray, 2007). Integral to sustainability is its focus on the long-term view, intricately weaving economic prosperity and environmental responsibility (Mehmood et al., 2022). Essentially, the crux of sustainability for a company or product lies in the ability to comprehensively recognise and navigate the diverse considerations that impact efficient resource utilisation or value addition (Alam et al., 2021; Rachuri et al., 2011). Sustainability embodies a wide spectrum of decision-making domains, encompassing ecological, social, and economic dimensions. Furthermore, the essence of sustainability involves selecting pertinent success metrics in line with the organisation's goals and performance standards (Kamali and Hewage, 2017). To embody the spirit of sustainability, a company or product must diligently address the trio of environmental, economic, and social dimensions, aligning their efforts with the foundational principles of this triad.

1. Environmental sustainability (Goyal et al., 2019): consumption of energy, global warming, non-human/human toxicity, air pollution, loss of ozone, depletion of resources etc.
2. Economic performance (Pissourios, 2013): sales revenues, added value, gross operating profit, financial position etc.
3. Social status (Enright et al., 2020): community involvement, access to resources, social responsibility, fair pay, working hours etc.

1.3 Circularity and sustainability

As defined, a CE embodies an economic paradigm grounded in strategic business approaches that surpass the traditional concept of *end-of-life*, replacing it with methods fostering waste reduction through material reuse, recycling, and remanufacturing throughout the production and consumption phases (Dominko et al., 2023). Encompassing various tiers including micro-level dimensions (individual products, companies, consumers), meso-level configurations (eco-industrial parks), and macro-level contexts (metropolitan areas, regions, and nations), CE is driven by the overarching objective of nurturing a resource-efficient economic framework across all levels (Kirchherr et al., 2017). However, the conceptual landscape of CE has expanded to accommodate a myriad of interpretations, reflecting a diverse range of perspectives, and allowing ample room for the implementation of various interventions (Blomsma and Brennan, 2017; Kirchherr et al., 2017).

Equally pivotal is the imperative to interlace the CE paradigm with other foundational tenets, notably sustainability (Blomsma and Brennan, 2017). This synergy between the

CE and sustainability is manifested as CE garners increasing prominence as a vehicle for fostering and maintaining long-term environmental and socio-economic well-being (Ghisellini et al., 2016; Rossi et al., 2020). Untangling the intricate interplay of divergent or convergent objectives, fostering synergies among policies, and directing efforts toward an enduring system demands a critical inquiry: does the pursuit of circular aspirations propel the system toward a nexus of sustainability or veer it off course? This discernment assumes a paramount role in charting a coherent trajectory, warranting a nuanced exploration of the interplay, congruences, and disparities between these two conceptual constructs. Such discernment is deemed critical not only for achieving conceptual clarity but also for elucidating the underlying motives and aspirations that underlie the use of these terms within the realms of political discourse and corporate initiatives (Geissdoerfer et al., 2017).

1.4 Assessment of CE

A growing concern among CE practitioners revolves around the practical implementation of conceptual frameworks and specific methodologies. Evidently, the need for a structured framework arises to quantitatively assess the effectiveness of indicators and material attributes, including factors such as reliability, reparability, recyclability, and the prudent use of dissipative materials. This meticulous analysis aims to unravel the cascading impact dynamics across both upstream and downstream segments of the value chain, while carefully balancing the repercussions across diverse assets and locations. It becomes apparent that the execution of CE strategies, without a robust monitoring ecosystem, risks generating suboptimal, less effective, or incongruous outcomes (Kirchherr et al., 2018). Within the complexity of circularity assessment methodologies, a convergence emerges, wherein various approaches align on core tools and criteria. Thus, a cohesive exposition of the fundamental principles underpinning circularity assessment comes to the forefront:

1. Use less: decreased resource needs for a given useable output (thermodynamic and eco-efficiency), allowing for a decline in mining operations and the associated effects from treatment, consumption, and throwing away.
2. Absorb circularities: utilisation of recycled resources, reuse, and energy recovery attempts to reduce the need for processing virgin materials and providing energy.
3. Generate circularities: the potential created by the product-system for materials to be reused and recycled, as well as for rubbish to be subjected to energy recovery.
4. Use of renewable energy sources: renewable resources can be exploited sustainably if the pace of regeneration does not surpass the rate of exploitation.

To mitigate the problem of redundant quantification, the circular flows generated by the product-system that subsequently reintegrate into the system as assimilated circularities are intentionally excluded from consideration. Additionally, the current phase of the methodology's development refrains from factoring in newly generated circularities for external systems (Merli et al., 2018).

1.5 Life cycle assessment

In the realm of the transportation industry, the incorporation of LCA appraisals holds critical significance in understanding its impact on the CE. Employing LCA-driven methodologies provides a systematic approach to addressing the complex interplay of environmental, social, and economic implications linked to various CE strategies. This meticulous approach gains particular importance when considering the distinct consequences of these strategies in emerging economies in contrast to their more industrialised counterparts (Pauliuk, 2018). Overlooking the integration of such a comprehensive and diverse perspective could lead to adverse outcomes across multiple segments of the transportation industry's value chain. The disparities in material and resource availability between emerging economies and well-established nations emphasise the importance of this undertaking. Specifically, certain emerging economies currently exhibit a heightened reliance on material and resource imports compared to many developed countries, owing to relative scarcity. As a result, extending the lifespan of material usage in some emerging economies remains an ongoing aspiration rather than a fully realised achievement (Maceno et al., 2023). The relevance of informal reuse and recycling sectors serves as examples of this phenomenon, with their growth trajectory serving as a prime illustration of this trajectory.

LCAs and methodologies rooted in LCA principles have emerged as pivotal instruments in steering the transition toward sustainable circular economies (Bhyan et al., 2023). The circularity paradigm serves as a conduit for generating income through a resource-efficient approach, bypassing the convoluted pathways inherent in a conventional linear economy, a characteristic evident in burgeoning emerging economies as well as well-established industrialised nations. In this capacity, it offers a discerning analysis of the intricate interplay of trade-offs among various impacts, including water consumption, energy utilisation, carbon dioxide emissions, material expenditure, and recyclable commodities, while considering the extensive social and economic ramifications of these intricate trade-offs (Peña et al., 2021). A crucial undertaking lies in the comprehensive contemplation of the economic, environmental, and social ramifications intrinsic to various alternatives throughout a product's lifecycle, encompassing domains such as electricity, paper, cotton, or durable plastic packaging (UNEP, 2020). The scope of waste is extensive, encompassing shifting climate patterns, water consumption trends, land use dynamics, and the ecological footprints manifested by litter in ecosystems. Simultaneously, a host of challenges, including resource scarcity, water supply coverage, sanitation facility accessibility, and labourer compensation, underscore the complex social and economic underpinnings (Wulf et al., 2018). Thoughtful consideration must extend to local manufacturing facilities, necessitating a concerted synergy with nearby suppliers to minimise material transit. Such an approach significantly influences the qualitative fabric and environmental implications of core products procured from local origins, thereby reverberating through socio-economic dimensions in the countries of the original suppliers, underscoring the gravity of these decisions.

1.6 LCA approach

Furthermore, significant progress has been made in advancing the frontier of knowledge towards the development of social LCA tools, a concerted effort aimed at orchestrating a seamless integration of the societal facet within the framework of LCA. This integrated approach fosters a holistic vantage point that encapsulates the societal component of the triple-bottom-line (TBL), thereby providing decision-makers with a comprehensive lens for informed decision-making (Walker et al., 2021; Dreyer et al., 2006). Despite the conceptual lucidity that LCA embodies, its practical implementation presents formidable challenges attributable to the voluminous corpus of data required for input parameters and the intricate web of interdependencies interwoven within. Notably, the journey toward sustainable LCA has gained increasing traction within the academic and research community, signifying a growing commitment to navigating these complexities. The imperative of LCSA vis-à-vis a product has assumed paramount significance, serving as a cornerstone for assessing its environmental impact in tandem with its societal implications.

Promoting sustainability within the domain of manufacturing requires a comprehensive and integrated approach that transcends the confines of product-centric considerations, extending its purview to encompass the entire spectrum of industrial processes implicated in its fabrication. This strategic paradigm mandates an all-encompassing outlook, one that not only includes the specific product under scrutiny but also entails a meticulous evaluation of the intricate tapestry of industrial processes that orchestrate its genesis. Such an approach must navigate a multifaceted terrain, spanning from the microcosm of a singular production line to the mesoscopic expanse of an entire manufacturing plant, and extending its tendrils to encompass the macrocosm of an enterprise at large, alongside all the interlacing constituents within the expansive supply chain (Figge and Hahn, 2006). At the core of this strategic architecture lies the imperative to infuse manufacturing processes with an enhanced ethos of environmental stewardship and safety assurance, particularly at the granular level of individual process operations. This transformative endeavour finds fruition through a combination of interventions, encompassing the adoption of cleaner energy modalities, the integration of renewable materials, curbing the deployment of hazardous substances, and the implementation of various environmental and safety augmentation strategies (Balasbaneh and Sher, 2022). As we navigate the intricate contours of manufacturing, a critical nexus emerges, wherein a constellation of discrete production stages converges to give birth to a cohesive production line – a pivotal linchpin in the architecture of systems-level orchestration. Within this crucible, the symphony of individual process performances merges, engendering a discernible impact on both the process-level efficiency and the overarching system's efficacy, culminating in a cascading influence on the overall sustainability trajectory of the end-product.

The integration of the TBL methodology marks a significant milestone in fostering the transition from a traditional linear life-cycle system to an innovative closed-loop material flow paradigm. This shift serves as a foundational pillar in advancing sustainability objectives essential for the development of robust and enduring products (Jawahir and Bradley, 2016). Employing a comprehensive set of metrics plays a vital role in evaluating the effectiveness, efficiency, and evolution of various strategic models, processes, products, and systems. A holistic approach to performance assessment necessitates the amalgamation of diverse metrics tailored to comprehensively assess the multifaceted aspects encompassing economic feasibility, environmental stewardship, and societal welfare, thereby embracing the complex tapestry that embodies holistic sustainability (Patterson et al., 2017). The meticulous orchestration of these metrics within an efficient and integrated framework is imperative, endowing decision-makers with the capability for discerning and prudent decision-making in the pursuit of enhanced performance (Labuschagne et al., 2005).

Within the landscape of sustainable manufacturing, a three-tiered perspective emerges, encompassing the product, the process, and the overarching system. This comprehensive outlook reaches its pinnacle when viewed through the lens of the holistic life cycle, spanning pre-manufacturing, production, utilisation, and post-utilisation phases—a narrative that mirrors the foundational principles of the TBL doctrine (Shuaib et al., 2014). The development of a more comprehensive methodology, the product sustainability index (ProdSI), as evidenced by the work of Shuaib et al. (2014), has effectively engendered an all-encompassing framework that intricately weaves the essential elements of the TBL imperative. Concurrently, parallel inquiries undertaken by researchers such as Lu (2014) have contributed significantly to unveiling an evaluative apparatus tailored to assess the sustainability performance of intricate manufacturing processes, contributing to an intellectual lineage characterised by a relentless pursuit of cohesive sustainability paradigms.

1.7 Product sustainability index

Shuaib et al. (2014) propose the ProdSI as a comprehensive framework aimed at evaluating the sustainability of products. This index has been developed through prior research endeavours, emphasising the establishment of a robust system for assessing various facets of a product's long-term viability. To quantitatively capture distinct dimensions of a product's sustainability, an extensive database of product sustainability measurements has been curated. The TBL approach encompasses more than seventy diverse indicators that collectively reflect the multifaceted nature of business operations (Boz, 2020). To delve into the nuanced aspects of product sustainability, these indicators are systematically categorised into sub-clusters. Each individual metric is tailored to address the unique attributes of a specific product, ensuring a customised evaluation. Primarily, the economic sphere encompasses three distinct clusters, contributing to the formulation of the economic index. Subsequently, five clusters are dedicated to the environmental domain, playing a pivotal role in constructing the environmental index. Lastly, five clusters are aligned with the societal dimension, significantly contributing to computing the societal index. Through an amalgamation of these indices, the comprehensive ProdSI for an electric vehicle product is derived.

Through an exhaustive review and meticulous analysis of existing product sustainability measurements, the framework of ProdSI was developed, as outlined by Shuaib et al. (2014). This development process took into account a spectrum of factors, including the TBL, the entirety of a product's life cycle, and the incorporation of the six core sustainability principles. Upon achieving the theoretically optimal scenario, the best-case scenario is attributed to each metric, thereby standardising the measured data on a scale of 0 to 10 (where a score of 0 corresponds to the most unfavourable scenario). It is noteworthy that a product would receive a score of 0 in case the manufacturing process entailed the direst circumstances imaginable. Subsequently, the culmination of the ProdSI for a specific product emerges from the amalgamation of the economic, environmental, and societal indices. In this context, each facet of the TBL holds equal significance. Employing subjective weighting methodologies, the evaluation of each aspect of TBL ensues, ultimately determining the relative significance of diverse clusters within each category.

2 Materials and methods

2.1 Research method

Bangladesh, an emerging nation, encompasses 12 City Corporations strategically located within its major urban centres. Khulna City Corporation (KCC) stands out as a crucial urban hub, tracing its path along the serene banks of the Rupsha-Bhairab River. Serving as a focal point for diverse activities including trade, governance, industry, education, and healthcare in the southwest region, KCC assumes a pivotal role in shaping the socioeconomic landscape of the nation. The city prides itself on a robust network of connectivity, intricately linking it to the national capital, Dhaka, and other prominent urban hubs via a sophisticated mesh of railways, waterways, and thoroughfares. While KCC strives to offer a comprehensive suite of urban amenities, its transportation infrastructure somewhat lags that of its metropolitan counterparts, as highlighted by Haque et al. (2018). A notable feature distinguishing KCC from its urban counterparts is its distinctive public transportation system. Within the ambit of the KCC, the primary modes of transportation include the Mahindra (Tempo) and the locally renowned easy-bike, as expounded by Hossain et al. (2019). Noteworthy is the extensive road network spanning a total length of 824.47 kilometres within Khulna, delineated into primary roads (74.81 km), secondary roads (181.94 km), and tertiary roads (567.62 km).

The survey was conducted with utmost care, involving the meticulous collection of data from drivers, proprietors, and manufacturers, employing a variety of techniques such as quantitative data collection and random sampling. The foundational data for this comprehensive study originated from an extensive reconnaissance survey involving a diverse cohort of local drivers, easy-bike proprietors, and manufacturers. The data collection phase spanned from April 2019 to November 2020, initiating the data collection in April 2019 to gather essential insights encompassing the social, ecological, economic, and environmental dimensions of the study area. A total of 200 easy-bike riders from Khulna City participated in the survey, providing their input through a carefully designed questionnaire. Both judgmental and convenience sampling techniques were employed to ensure a representative spectrum of participants. Notably, the study integrated expert opinions to determine the weight assigned to distinct clusters and sub-clusters. Three experts from the production and supply domain, along with an additional expert in the field of technology, were consulted to contribute their valuable insights to this crucial aspect of the research. The metrics and clusters utilised in this study were adapted from the seminal works of Huang and Badurdeen (2016) and Shuaib et al. (2014), affirming the robustness and academic rigor of the methodological framework employed.

In the past year, Bangladesh has experienced a notable transformation in its urban transportation sector, signifying a period of significant change. A key highlight of this shift has been the introduction of an innovative transportation mode known as the *easy-bike*. This novel battery-powered three-wheeler vehicle boasts the capacity to accommodate up to six passengers, showcasing substantial improvements in terms of speed and cost-effectiveness compared to its predecessors (Hu et al., 2020). This burgeoning sector not only holds the promise of fostering self-sustaining businesses but also presents lucrative prospects within diverse global markets. The industry's potential for future exports is accentuated by its proficient workforce and robust technological advancements. Leveraging the available technology and resources within the region, Bangladesh is positioned to take the lead in electric vehicle production, with the easy-bike spearheading this transformative journey (Plötz et al., 2017). Comprising a streamlined chassis and three robust wheels, the easy-bike is constructed with cost-efficiency in mind, utilising mild steel for the chassis and galvanised iron pipes for the body. With a slightly aerodynamic design, the vehicle measures 287 × 105 × 178 cm, although specific dimensions may vary based on individual manufacturers' designs.

The easy-bike is powered by a reliable waterproof direct current (DC) motor, which derives its energy from lead-acid batteries, effectively utilising electricity for its motion (Rana et al., 2013). It is crucial to recognise that the reliance on external fuel procurement for electricity generation introduces a dependency on regional geopolitical dynamics, which might indirectly impact the trajectory of the industry. The content of this article represents a comprehensive assessment, encompassing various aspects of the easy-bike's design, construction, and operation. This evaluative effort was conducted with a firm commitment to understanding the complex interplay of factors that collectively shape the landscape of the vehicle industry, duly acknowledging the intricacies inherent to the manufacturing sector.

The assessment of the easy-bike's product sustainability, as an electric vehicle operating within the region, is conducted through a customised set of parameters tailored to its specific characteristics. This comprehensive evaluation spans the various stages of the vehicle's life cycle, including pre-manufacturing, manufacturing, usage, and post-use phases. The assessment encompasses a range of critical aspects of the product life cycle, such as direct and indirect cost considerations, service, and maintenance requirements, as well as end-of-life scenarios, repurposing efforts, and the potential for remanufacturing. The values assigned to indicators, which play a crucial role in gauging the sustainability quotient, are derived meticulously from a diverse array of both internal and external data sources. These sources encompass a spectrum of functions covering various product dimensions, including product design intricacies, operational considerations, and the underlying LCA. A robust evaluative framework, supported by a five-tier hierarchical structure, facilitates a comprehensive assessment of the viability of the production line or extended plant operations.

The assessment process begins with an exploration of fundamental metrics, providing a nuanced understanding of specific performance parameters. Expanding on this foundational groundwork, the evaluation delves into the analysis of sub-clusters and clusters, ultimately leading to the quantification of sub-indices. These sub-indices, each representing dimensions encompassed within the TBL framework, are computed independently for each facet of the TBL trifecta. The pinnacle of this evaluative structure culminates in the synthesis of these sub-indices, resulting in the derivation of a comprehensive index that effectively encapsulates the multifaceted nuances of performance. In essence, this systematic evaluation framework serves as a valuable tool, facilitating a comprehensive understanding of the easy-bike's sustainability prowess, woven intricately throughout its various life cycle stages and dimensions.

2.2 Data normalisation for TBL

Implemented on a standardised scale ranging from 0 to 10, the normalisation technique aligns consistently with empirical data, ensuring an accurate representation of each individual metric. This scoring mechanism assigns a score of eight or higher, denoting an *excellent* status, while a score of six indicates an *acceptable* state. A score of four signifies an *average* standing, whereas a score of two or below highlights an *unacceptable* condition, necessitating immediate remedial action. The process of normalising scores for different scenarios adheres to established methodologies. However, it is essential to recognise that certain aspects, such as the impact on human health and broader societal implications, may present challenges in precise evaluation. In such nuanced situations, the use of subjective normalisation methodologies proves to be a prudent approach. These subjective normalisation scores, differing from their objective counterparts, may assume a discrete or stepwise nature, particularly when navigating through specific temporal contexts.

2.3 Weighting and score aggregation for TBL

The assignment of weighting factors to normalised scores is crucial for appropriately calibrating outcomes in terms of severity and significance. Various effect assessment systems employ different methodologies for allocating weights, each characterised by distinct considerations. Among the most widely recognised and utilised weighted methods, three approaches prevail: equal weighing, subjective weighing, and analytical-weighting approaches. Equal weighing involves assigning identical weight to each metric within a cluster, implying an equivalence in the significance of all constituents. This method is suitable when the relative value of each metric is inconsequential or when the emphasis does not lie on the relative importance of measurements. On the other hand, subjective weighting stems from data derived from statistics, surveys, and questionnaires, which are subsequently linked to subjective valuations of an element's worth and relevance. This often encompasses input from stakeholders, clients, industry collaborators, experts, manufacturers, and governmental bodies. The cumulative weighted factors are computed based on the outcome of this comparison.

While the analytical approach is more impartial than its counterparts, it is also more intricate and resource-intensive, demanding a substantial investment of time and effort. Ensuring uniformity in the normalisation and weighting methodologies is crucial when scrutinising the sustainable performance of diverse correlated entities, utilising the ProdSI to facilitate comparative sustainability assessments. However, it is noteworthy that the International Organization for Standardization (ISO) discourages the application of weighted ratings in public product comparisons, citing subjectivity as a fundamental concern (ISO, 2006). Despite its status as one of the less developed effect assessment techniques, weighting is extensively employed in life-cycle analysis and product sustainability appraisal, posing formidable challenges in its implementation. Consequently, the amalgamation of normalised data and applied weighting criteria culminates in the comprehensive construction of a sustainability index score, a process that can be succinctly articulated through equations delineating the interrelationships between variables (Zhang et al., 2019).

- Sub-clusters level

$$Y_{ij} = \sum_{m=1}^{n} w_{ij_m} \frac{Z_{ij_m}}{N_{ij_m}} \tag{1}$$

Here,

Z_{ij_m} is the m^{th} individual metric under sub-cluster Y_{ij}

Y_{ij} is the j^{th} sub-cluster under i^{th} cluster X_i

w_{ij_m} is the weighting factor for individual metrics Z_(ij_m)

n is the number of individual metrics under sub-cluster Y_{ij}

N_{ij_m} is the normalising constant for the m^{th} individual metrics under sub-cluster Y_{ij}.

- Cluster level

$$X_i = \sum_{j=1}^{k} w_{ij} Y_{ij} \tag{2}$$

Here,

X_i is the i^{th} cluster

w_{ij} is the weighting factor for sub-cluster Y_{ij}

k is the number of sub-clusters under cluster X_i.

- Sub-index level

$$Q_p = \sum_{i=1}^{s} w_i X_i \tag{3}$$

Here,

Q_p is the p^{th} sub-index

w_i is the weighting factor for cluster X_i

s is the number of clusters under sub-index Q_p.

- ProdSI

$$ProdSI = \sum_{p=1}^{t} w_p Q_p \tag{4}$$

Here,

w_p is the weighting factor for the sub-index

Q_p is the number of sub-indices.

The approach outlined by Shuaib et al. (2014) for TBL research has formed the groundwork for the normalisation strategy, which has subsequently been customised to scale the normalisation metrics between 0 and 10. The allocation of these metrics is influenced by various dynamics, including business strategies, regulatory frameworks, competitive landscapes, and industry benchmarks, emphasising the relative significance of each aspect within the ProdSI hierarchy. Equal weights have been assigned to the three sub-indices at the highest tier – namely, *economy*, *environment*, and *society* – reflecting a perceived equality in their respective levels of importance. The tabulated representation demonstrates the distribution of normalising values across different tiers of variation, with the maximum sub-cluster matrices being informed by percentage values. Subjective criteria related to certification and regulation, employment practices, use of hazardous materials, and product disposal are contrasted with objective measures, often presented as binary values (yes or no).

Cluster weights are determined based on the priorities established by managers for each cluster, as reflected in the perspectives of the respondents. With these weightings in place, the adjusted, normalised, and weighted indicators were averaged to evaluate the ProdSI for the range of five baked goods produced by the company. The resulting graphical representation illustrates the outcomes, starting from the sub-cluster level and progressing to the final computation of the ProdSI. The normalised metrics, after adjustments, are depicted on a graduated scale ranging from 0 to 10. In alignment with the reasoning at the top tier, where equal importance was identified among the three sub-indices (*economy*, *environment*, and *society*), the tabular representation demonstrates the allocation of normalisation values across various variations. Simultaneously, certain qualitative criteria such as certification and regulation, the presence of child labour, the use of hazardous materials, and product disposal are delineated through objective binary measures (Shuaib et al., 2014).

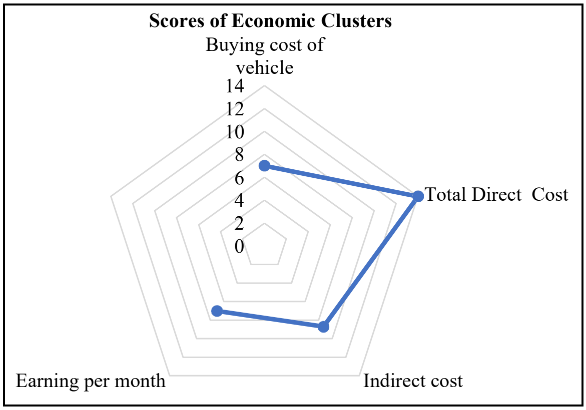
2.4 Economic sustainability assessment

The costs associated with electric vehicles encompass direct expenses related to operational energy, labour directly involved in the process, and the expenses of raw materials. Additionally, the scope extends to include a multitude of hidden indirect expenditures, where cost figures are sometimes strategically managed to conceal the true financial outlays, along with a range of ancillary elements. Emissions resulting from the interaction of energy use, labour inputs, and the generation of waste byproducts further contribute to the overall environmental impact. The aggregation of all relevant expenses converges to determine the comprehensive production cost. A crucial step in this evaluative process involves comparing the collected data with a benchmark, against which the data is examined and subsequently standardised, using a scale with a maximum score of 10. This normalisation procedure not only facilitates data comparison but also assists in identifying potential anomalies within the dataset, thereby enhancing the rigor of the analysis.

Table 1 Economic clusters, sub-clusters, and metrics

Cluster	*Sub-cluster(s)*	*Metric(s)*
Investment(s)	Buying cost of vehicle	Cost of buying vehicle
Direct and indirect costs	Direct costs	Licensing cost
		Cost for charging
		Cost for renting the parking lot
	Indirect costs	Cost of depreciation
		Servicing cost
		Maintenance cost
		Repairing cost
		Cost of buying new parts
Benefits and losses	Earnings per month	Earnings per month

Figure 1 Economic sustainability scores (see online version for colours)



The aggregation of the normalised scores leads to the determination of the sub-index score, achieved through an equitable weighting methodology. In the assessment of production expenses, a comprehensive aggregation of all relevant cost data is undertaken, considering various cost components from a holistic perspective. The economic feasibility analysis of the easy-bike manufacturing line under consideration is elucidated in Table 1.

2.5 Environmental sustainability assessment

An environmental assessment is undertaken, encompassing a comprehensive examination of the implications arising from the inputs and outputs linked to the manufacturing line. The inputs encompass crucial factors such as materials, energy, and power resources, while the outputs encompass waste materials and emissions generated during the production process.

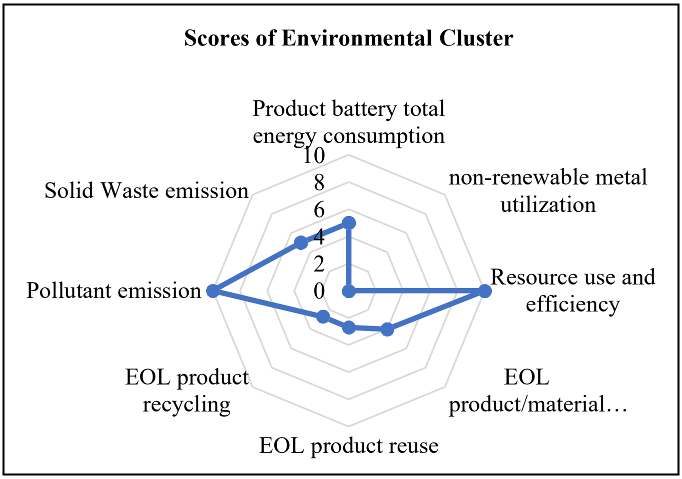
Table 2 Environmental clusters, sub-clusters, and metrics

Cluster	*Sub-cluster(s)*	*Metric(s)*
Energy use and efficiency	Product battery total energy consumption	Power/electricity consumption
Material use and efficiency	Durable renewable/non-renewable metal utilisation	Non-renewable metal uses
Resource use and efficiency	Resource use and efficiency	Except for electricity any other non-renewable harmful resource us
Product EOL	EOL product/material recovery	Products dis-assimilability
	EOL product reuse	Ratio of EOL product reused
	EOL product recycling	Ratio of product/material recycled
Waste and emission	Pollutant emission	Toxicity generation
		Heat generation
		Noise generation
	Solid waste emission	Reusability of the parts rather than throwing to rubbish

The proposed methodology entails a comparison of the measured data with benchmark data to derive the normalised score for each metric. Subsequently, the normalised score is aggregated with the sub-index score, computed using the equal weighting approach based on the normalised score.

Table 2 provides a concise summary of the sustainable environmental assessment of the manufacturing process for the easy-bike.

Figure 2 Environmental sustainability scores (see online version for colours)



2.6 *Societal sustainability assessment*

When examining social sustainability within the workplace, significant emphasis is placed on the well-being and safety of the workforce, who represent the immediate stakeholders within the manufacturing process.

Table 3 Social clusters, sub-clusters, and metrics

Cluster	*Sub-cluster(s)*	*Metric(s)*
Community welfare	Drivers' health	Human health
		No. of accidents/ the injury rate in a year
		Work-related illness
		Stress level in comparison to health
End-of-life impact	Product EOL social impact	Product disposal is risky to the community
Product quality and durability	Repair and maintenance	Product maintainability
		Product reliability

To obtain the normalised score, each measured data point is evaluated against the benchmark and subsequently standardised. The resultant normalised score is then integrated with the sub-index score, computed using the identical weighting methodology as the normalised score.

Table 4 Aggregated TBL scores

ProdSI	*Value*	*Sub-index*	*Values*	*Cluster*	*Value*	*Sub-cluster*	*Value*	*Metric*	*Normalised*
Product sustainability index	7.46	Economic	8.62	Investment	7	Buying cost of vehicle	7	Cost of buying the vehicle	7
				Total direct and indirect costs	12.41	Direct costs	14	Licensing cost	8
								Cost for charging	5
								Cost for renting the parking lot	7
						Indirect costs	8.7	Cost of depreciation	8
								Servicing cost	4
								Maintenance cost	7
								Repairing cost	6
								Cost of buying new parts	4
				Benefits and loss	7	Earnings per month	7	Earnings per month	7
		Environmental	7.88	Energy use and efficiency	5	Product battery total energy consumption	5	Power/electricity consumption	5
				Material use and efficiency	0	Durable renewable/non-renewable metal utilisation	0	Non-renewable metal uses	0
				Resource use and efficiency	10	Resource use and efficiency	10	Except electricity any other non-renewable harmful resource us	10
				Product EOL	9.4	EOL product/material recovery	4	Products dis-assimilability	10
						EOL product reuse	2.7	The ratio of EOL product reused	7
						EOL product recycling	2.7	The ratio of product/material recycled	9
				Waste and emission	15	Pollutant emission	10	Toxicity generation	10
								Heat generation	10
								Noise generation	0
						Waste emission	5	Reusability of the parts rather than throwing to rubbish	10
		Social	6.11	Community welfare	26	Driver' health	10	Human health	10
							5	No. of accidents/ the injury rate in year	5
							8	Work-related illness	8
							3	Stress level compared to the health level	3
				End of life impact	10	Product EOL social impact	10	Product disposal is risky to the community	10
				Product quality and durability	9	Repair and maintenance	9	Product maintainability	6
								Product reliability	3

Figure 3 Social sustainability scores (see online version for colours)

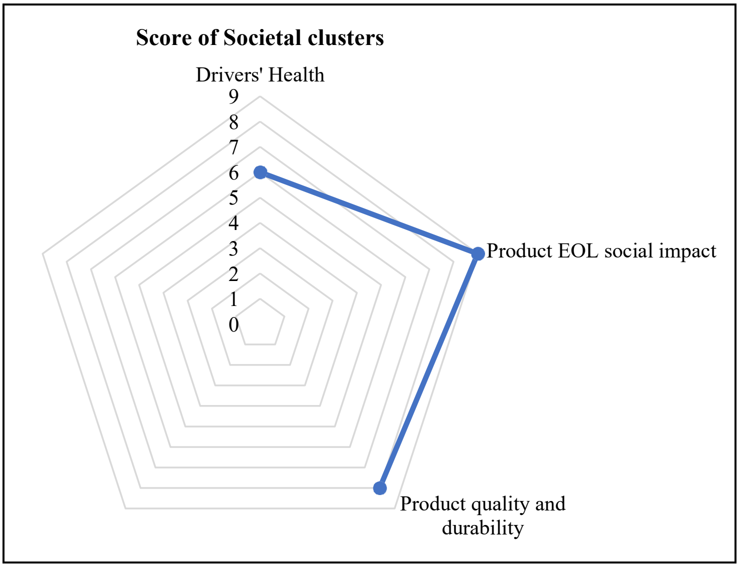
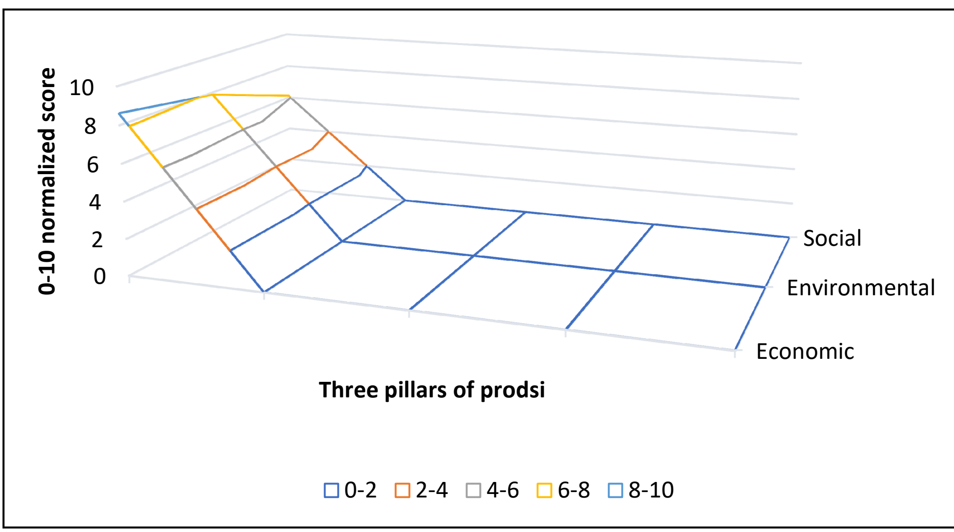


Table 3 illustrates the macroeconomic impact of easy-bike production.

Figure 4 Product sustainability (ProdSI) scores (see online version for colours)



Across the three pillars, the economic dimension demonstrates a consolidated score of 8.62, with the profit and loss cluster registering an individual score of 7, thus emphasising the robust economic feasibility of the local electric vehicle. Similarly, the investment in monthly earnings cluster obtains a score of 7, signifying the satisfactory operational performance of the vehicle within the context of a developing nation. As for the environmental pillar, the cumulative score amounts to 7.88, indicating a commendable evaluation on the 0 to 10 normalised scale. Notably, specific focus is directed towards energy and metal utilisation, with scores varying from 0 to 5. The electric vehicle notably relies significantly on non-renewable energy sources, coupled with identifiable consumption of non-renewable metals, notably electricity and iron. Conversely, the evaluation of the product's end-of-life phase reflects an exceptionally positive perspective, attaining an impressive score of 9.4. This suggests a seamless process of reuse and dismantling during the product's end-of-life phase, without any detrimental societal impacts. Despite these favourable assessments, concerns arise from pollutant indicators, particularly in the realm of noise levels, as evidenced by the lower score of 0. This underscores the heightened noise levels associated with the electric vehicle, thereby necessitating focused attention on noise mitigation strategies and technological interventions.

Within the societal pillar, an observed score of 6.11 raises notable concerns, drawing attention to metrics such as the annual rate of accidents or injuries, work-related health issues, and stress levels in relation to overall health, all falling within the 0–5 score range. Conversely, the evaluation of product end-of-life maintenance and its broader societal impact yields positive scores, indicating the vehicle's positive presence within the community. Upon integration with the designated weightings (0.33 for the environment, 0.33 for the economic, and 0.33 for the social dimensions), the resulting overall TBL score culminates at 7.46. In assessing the sustainability of the easy-bike/electric vehicle, this score signifies a commendable level of sustainability for the product across economic, environmental, and social dimensions, highlighting its satisfactory performance within these realms.

3 Discussion

The current research delves into an extensive assessment focused on evaluating sustainability across the entire life cycle and local economic development in the Khulna city region. Although sustainability is universally acknowledged as a guiding principle among all stakeholders, the formal evaluation and quantification of sustainability performance, especially regarding goods and processes, remain challenging. Methodologies and tools for sustainability advancement vary across the three sustainability dimensions. Presently, the management of environmental aspects is relatively robust, while the advancement of economic and social indicators, along with their corresponding evaluation techniques, necessitates significant scientific progress. Utilising the concept of life cycle thinking presents itself as a constructive strategy to foster sustainable production and consumption. However, it is imperative to interpret its outcomes judiciously, considering their inherent limitations. In essence, the concept of LCSA emerges as the most optimal trajectory. To ensure accuracy and reliability, the adoption of a life cycle approach is indispensable across all aspects of sustainability, enabling the delivery of precise and credible results.

Developing a robust LED (Local Economic Development) strategy within the Khulna region assumes paramount importance in orchestrating a concerted effort. This involves the systematic identification of all relevant stakeholders from various spheres – including individuals, enterprises, or entities from the public, private, or non-profit sectors. These stakeholders, with vested interests and capabilities, are well-positioned to significantly contribute to the conception and execution of the strategy. By establishing a strong foothold in the domain of leadership and accountability, particularly through close collaboration with the local government apparatus, the strategy can gain substantial momentum. Anchoring the implementation plan within the confines of pivotal administrative bodies, such as the mayor's office, enhances the prospect of garnering high-level endorsement and support. Active stakeholder involvement plays a vital role in conferring legitimacy to the entire process, serving as a wellspring of knowledge and expertise that amplifies the strategy's comprehensiveness and effectiveness.

Furthermore, the utilisation of public-private partnerships (PPPs) could serve as a potent avenue for enhancing both knowledge and financial resources necessary for the advancement of indigenous bicycle manufacturing at the local level. The private sector, owing to its intrinsic market-driven orientation, is well-placed to possess a more insightful understanding of the authentic vibrancy of the local economic landscape in relation to its competitive stance. Notably, the private sector remains an instrumental engine in propelling job creation, thus emphasising its pivotal role. By ensuring comprehensive involvement of the governmental apparatus, a more encompassing and harmonised approach could be fostered. This could, in turn, create a conducive environment for garnering enhanced endorsement for funding propositions tailored towards nurturing the growth trajectory of the rudimentary bicycle manufacturing enterprise. It is crucial to underscore that the foundation of community-driven development assumes a pivotal position within the framework of Khulna city's Local Economic Development (LED) paradigm, emblematically exemplified by the burgeoning landscape of the uncomplicated bicycle industry.

The proposed strategies outlined in the research represent pivotal steps toward fostering sustainable development and economic growth within the Khulna city region. By integrating LCSA methodologies, the study effectively underscores the significance of taking a comprehensive approach to sustainability, thereby providing a robust framework for evaluating the various dimensions of sustainable practices. This holistic perspective facilitates a nuanced understanding of the intricate interplay between economic, environmental, and social factors, thereby enabling policymakers and stakeholders to make informed decisions aimed at promoting long-term sustainability. Moreover, the emphasis on stakeholder engagement and collaboration through PPPs highlights the essential role of inclusive governance and shared responsibility in driving sustainable development initiatives.

However, it is imperative to acknowledge the potential challenges associated with implementing these strategies, including the need for effective coordination and communication among diverse stakeholders, as well as the allocation of adequate resources and funding to support sustainable initiatives. Furthermore, ensuring the integration of sustainable practices within the existing regulatory frameworks and policies poses an additional complexity that requires careful consideration and strategic planning. This necessitates the development of tailored approaches that account for the unique socio-economic and environmental context of the Khulna city region, thereby fostering the creation of a more resilient and sustainable local economy.

4 Conclusions

The fundamental objective of this research was to elucidate the practical implementation of the circularity concept in the context of the Khulna city area, utilising the methodologies of LCSA. To achieve this goal, the study extensively employed various evaluative frameworks commonly applied at the urban scale. Through comprehensive fieldwork, the empirical investigation uncovered the intricate interconnections between CE dynamics and the broader spectrum of life cycle sustainability within Khulna city's transportation domain, a significant sphere of influence within the region. The concept of the CE is inherently intertwined with the comprehensive fabric of life cycle sustainability inherent in Khulna city's transportation landscape. The convergence of environmental, economic, and societal considerations inherent in the CE resonates harmoniously with the framework of the TBL, which has effectively guided the benchmark for evaluating sustainability. The initial step in the ProdSI framework involves the identification, customisation, and delineation of context-specific metrics tailored to each unique scenario. These metrics, along with their calibration and overall aggregation techniques, are inherently dependent on the product type and industry context. It is noteworthy that the identification and definition of metrics can be substantially reinforced by industry standards, legislative mandates, expert perspectives, and scholarly discourse.

The systematic pursuit of additional case studies, undertaken in a concerted manner, serves as a catalyst in formulating industry-specific, standardised indicators encapsulating product sustainability. Within the broader context of a nation's progress, the transportation ecosystem assumes a pivotal role, significantly contributing to economic prosperity and fostering balanced development. Therefore, it is imperative for the transportation landscape to seamlessly align with the ever-evolving requirements of the region, as its functionality stands as a crucial element for Bangladesh's trajectory of economic advancement. In this light, a critical imperative emerges for the Bangladeshi government to carefully devise and implement a tailored roadmap, catalysing the proliferation of the easy-bike phenomenon. This can be tangibly achieved through the enactment of strategic legislation that designates the easy-bike as an official mode of transportation across both rural hinterlands and urban enclaves, effectively catalysing a transformative shift in the nation's mobility paradigm.

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