



# How Can Collaborative Circular Economy Practices in Modular Construction Help Fédération Internationale de Football Association World Cup Qatar 2022 to Achieve Its Quest for Sustainable Development and Ecological Systems?

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Embarking on the World Cup journey with circular collaborative strategies can positively impact the environment and socioeconomic outcomes to prosper development at the center of sustainability. World Cup mega-events are set with overriding priorities in cutting down environmental footprints to accelerate sustainable development across the Fédération Internationale de Football Association movement to leave an enduring legacy post-event in global sports. This paper conducts the first of its kind comprehensive critical analysis on ecological quality in life cycle impact assessment for 2022 Fédération Internationale de Football Association World Cup modular container stadiums in Qatar. A “cradle-to-cradle” life cycle assessment, including the material and resource production, construction, operation, and end-of-life (EOL) phase, is analyzed in this study, taking the case of Ras Abu Aboud stadium. Ecoinvent v3.7.1 life cycle inventory database was used to quantify the ecosystem damage-related impacts. Two scenarios were considered for the operation phase: scenario 1 (single year of operation) and scenario 2 (30 years of operation). A sensitivity analysis was used to understand the extent of impact per category indicator subject to material quantity variations. The results showed that the planned circularity contributed to savings in the EOL phase of more than  $4.26 \times 10^7$  species.year compared with 1.7 species.year across the overall life-cycle impacts. Several perspective-based circular and sharing economy scenarios were assessed

to reveal the benefits of circular collaborative economy applications in leveraging possible ecological burdens before, during, and post-mega events in sustainable construction. This research acts as a backbone for future single-sport mega-events to attempt to transition to a carbon-neutral, fully sustainable event with an everlasting legacy.

**Keywords:** collaborative circular economy, FIFA world cup, life cycle assessment, sharing economy, sustainability, sustainable development

## INTRODUCTION

### Background

Organizing the 2022 Fédération Internationale de Football Association (FIFA) World Cup™ seals a historical landmark in the epic records of the oil-rich state of Qatar, with profound implications on mass tourism, culture, service provision, construction, and sustainable development (Qatar2022, 2020a). Sustainability has become the major concern in societies worldwide (Kucukvar et al., 2014; Alsarayreh et al., 2020; Kutty et al., 2020a), of mega-events accounting for several positive and negative impacts both locally and globally (Death, 2011). The threats triggered by infrastructure development and mass tourism in mega-events are the associated carbon, material, and ecological footprints that emanate into irreversible environmental (e.g., ecosystem damage and resource depletion) and social impacts (e.g., human health damage) (Ahmed and Pretorius, 2010). Acquiring an egalitarian balance between the infrastructure development standards and regional urban planning directives with global sustainable development agenda 2030 and FIFA World Cup regulations can often be challenging. A circular economy (CE), a paradigm well sought in contrast to the traditional “take, make, dispose” linear economic system, is an answer to bring in balance to the infrastructure development and the associated waste accumulation at multiple stages of the construction value chain (Ellen Macarthur Foundation, 2021). Circularity in the early planning phase of the value chain is required to support sustainable initiatives that guarantee reduced waste at the end of life, with prospects of reuse and recycle to result in zero waste (Onat et al., 2019). Focusing on reutilizing the EOL waste as raw materials for new construction projects can downsize the ecological footprints, a collaborative consumption initiative (Kutty et al., 2020a).

In an attempt to achieve an equitable balance between the socioeconomic outcomes and ecological damages inflicted by mega-events on the host and neighboring territories, the FIFA World Cup 2022 targets to reduce the global carbon and ecological footprint impact, adopting various measures at regional, national, and international levels (Qatar2022, 2020b). One of the propound attempts is the design and construction of modular stadiums (Manni et al., 2018; Al-Hamrani et al., 2021). The Ras Abu Aboud (RAA) Stadium is one of the prominent examples in this respect, with a unique architectural design that will completely be dismantled post-World Cup (Qatar2022, 2020c) to attain sustainable outcomes. However, the ecological impacts of World Cup sporting events have not been fully understood (MezaTalavera et al., 2019). Moreover, how the socioeconomic and cultural impacts can foster sustainable

behaviors worldwide through collaborative practices needs to be further explored. Mega-events broadcast socioecological values and practices with carrying out the transition to sustainable behavior by showcasing innovative solutions, using supra-political levers to move toward sustainable living and consumption practices (Liang et al., 2016; Geeraert and Gauthier, 2018). Sharing and repairing activities can foster circular societal shifts at individual and community levels. However, to realize this potential, key actors need to be aware of associated risks and find ways to circumvent those while maximizing the benefits of sharing and repairing (MezaTalavera et al., 2019). On the other hand, concerns have been raised about, for example, public safety, privacy, and limited liability of sharing organizations (Mol and Zhang, 2011).

Integrating mega-sporting events with circular collaborative strategies can positively impact socioeconomic outcomes and prosper development at the center of sustainability (Manni et al., 2018). The state-of-the-art stadiums, demountable infrastructures, energy-efficient mass rapid transit systems, and innovative cooling technologies can support the transition of the host nation to an advanced sustainable circular collaborative economy, with a judicious recycle and reuse strategy pre- and post-event. Reimaging legacy during, before, and after mega-events through sustainable circular collaborative practices is a challenge that comes with impetus opportunities. These untapped opportunities must be untwined through critical analysis of the ecological damage points from the life cycle perspective of a cradle-to-cradle. In this regard, a “cradle-to-cradle” life cycle assessment to measure the midpoint environmental and endpoint ecosystem quality damage point is presented in this article. The reduced ownership and distributed utilization of assets to generate value through collaborative and circular initiatives are also discussed from a socioeconomic perspective in this paper, taking the case of the RAA Stadium, Qatar.

## LITERATURE REVIEW

### Life Cycle Influence Assessment

Life-cycle assessments (LCA) are methods to identify the existence or cradle-to-grave effect on creating, promoting, transportation, and delivering objects along the system cycle (Ekvall and Finnveden, 2001). The methodology considers structures and secret non-market movements of raw, intermediate product inputs and wastes and other mass and energy processing associated with the “product chain or method” (Ayres and Kneese, 1969). In some instances, the LCA

**TABLE 1 | (A) Midpoint-oriented LCIA methodologies.**

Methodology	Midpoint Impact classes	Protection area
CML	Mandatory effect categories include abiotic degradation, land rivalry, air pollution, underwater aquatic ecotoxicity, seawater ecotoxicity, climate change, ozone layer depletion, coastal ecotoxicity, photo oxidizing agent formation, and eutrophication. Optional types of impacts: life-supporting loss feature, habitat loss, ecotoxicity of freshwater sediments, ecotoxicity of aquatic sediments, radioactive ionizing, malodorous air effects, pollution, thermal energy, loss of life, deadly, non-letteral, biotic degradation, drying, and muddy water (Bribian et al., 2009).	Health of humans, nature, atmosphere of people, human capital (Gernuks et al., 2007).
EDIP 2003	Global heat, ozone loss, acidification, ground eutrophication, marine eutrophication, creation of photocatalytic ozone, human pollution, ecotoxicity, and sound pollution (Bovea and Powell, 2016).	Eco structure and services Human Welfare (Gebreslassie et al., 2009)
TRACI (Bare, 2002).	Acidification, eutrophication, cancers of human health, non-cancer human health, toxins of population health, ecological pollution, and reduction of fossil fuels (Finnveden et al., 2009).	Human well-being, climate, and services human health (Bellekom et al., 2006).

Methodology	Endpoint impact classes	Protection area
<b>(B) Endpoint-oriented LCIA methodologies</b>		
E199	Acidification, soil depletion, cancer-causing, environmental toxicology, ionizing radiations, ecotoxic, excessive land utilization, mineral wealth, fossil assets (Tillman, 2000).	Public health and ecosystem (De Haes et al., 2004).
EPS 2000	Expectation of survival, severe illnesses, mortality rates, serious disruptions, potential for crop disturbance, production of timber, fish, and meat processing capacities, potential for ionic base species, irrigation water capacities, extinguishing biodiversity share, reduction of elementary supplies, fossil reserves depletion (carbon), depletion of conventional reserves (oil) (Pennington et al., 2004).	Human well-being, potential for ecosystem development, abiotic energy, and biodiversity (Jolliet et al., 2004).
Eco Scarcity	Ozone degradation, formation of photochemistry-based oxidants, respiratory impact, air contamination, seawater pollutants, nuclear emissions, marine cancer, soil pollution, municipal (reaction) waste, toxic waste (subterranean), nuclear waste, groundwater use, shale, primary energy supplies "Damage categories are determined according to political agenda of corresponding country or region" (Ardente et al., 2008).	Public health and ecosystem (De Gracia et al., 2010).
JEPIX	Ozone degradation, formation of photochemistry-based oxidants, respiratory effects, air contamination, seawater pollutants, nuclear emissions, marine pollution, soil pollution, municipal (reaction) waste, toxic waste (subterranean), nuclear waste, water use, shale, primary energy supplies (Menoufi, 2011).	Public health and ecosystem (Norris, 2002).

procedure includes comparing a few options that are meant to have a comparable consumer service. The LCA is led to look for responses to questions such as: how to equate energy usage and possible damages of two separate production processes for the same product (Fischer-Kowalski and Weisz, 1999); what are the benefits of technical change; what are the relative impacts to the overall pollution from the various phases of this product life-cycle (Fischer-Kowalski and Haberl, 1993)?

The life cycle influence assessment (LCIA) transforms "stock" sources to simplified metrics. LCIA has two approaches: trouble-based (medium) and harm-based approach (endpoints) (Haas et al., 2005). In a problem-based approach, flows are assembled into ecological issues that fall under specific themes. The themes discussed in most previous LCIA studies include greenhouse impacts, degradation of natural resources, stratospheric depletion, rising temperatures, photochemical ozone production, ocean acidification, human toxicity, and marine toxicity (Haberl et al., 2004). These approaches seek to clarify the scope of several hundred flows to several

fields of importance for the community (Weisz, 2006). The approaches that focus on damage often begin by categorizing a scheme's flow into separate ecological topics; however, the design was harmful to each environmental topic as per its impact on human and ecosystem health or damaged assets (Miyazaki et al., 2004; Tadeu et al., 2015). LCIA has been established as a knowledge and context-spreading method for life cycle inventory (LCI) data, relating mainly to power and size (Finnveden, 1997). It does not mean that the goods or devices analyzed have effects because LCI proves that such pollutants are related to some environmental issues or influence groups. However, it ensures that pollutants that lead to a stream of emissions equally known to apply to these environmental concerns or divisions are produced during the life cycle (Huberman and Pearlmutter, 2008). LCIA is thus used as a method to decide the degree to which a specific substance, method, component, or pollution can be related. Furthermore, the midpoint- and endpoint-oriented methods are discussed in **Table 1** in detail.

## Why Collaborative Circular Economy in Sustainable Construction?

By utilizing enormous quantities of natural resources, the construction industry leads to resource shortages and creates vast quantities of waste that lead to a substantial share of the environmental effects caused by the demand of an increasing world population. Many construction materials require vast quantities of energy and materials supplies (Kapsalis et al., 2019). Nevertheless, these products are either down cycled or scrap after construction. Subsequently, the construction industry can only use a limited proportion of the commercial benefit and strength of the building products (Eberhardt et al., 2019). To satisfy future requirements, the need for increased utilization of services would also increase alongside increasing human needs. By recirculating building materials, the concepts of circulatory economics can theoretically reduce to a minimum of the pending problems arising from the construction industry (Berg et al., 2018). Established mechanic technologies, for instance, may allow for the reassembly of materials and parts through reuse in corresponding construction projects, thus theoretically extending their service life (Elia et al., 2017).

The definition of collaborative circular economy (CCE) has recently been debated at different levels by various groups (Anastasiades et al., 2020). A collaborative economy will be a new owning economy as an “economic system of decentralized networks and marketplaces that unlocks the value of underused assets by matching needs and haves, in ways that bypass traditional middlemen” (Botsman and Rogers, 2011). In meta-review of the CCE concept, formed keys feature for collaborative platforms: (1) core business idea involves the value of unused or underutilized assets, (2) organizations involved in collaboration principles of transparency and authenticity, (3) the providers on the chain supply side should be “valued, respected and empowered,” for making consumers’ lives environmentally, economically, and socially better, (4) all customers and providers should have benefited from goods and services access, and (5) CCE platform creating distributed marketplaces, decentralized networks with creating a sense of “collective accountability and mutual benefit” (Botsman and Rogers, 2011). To save energy and encourage the optimal utilization of resources, citing concerns over excessive resource usage in the building industry without respect for external consumption of resources, a paradigm change of the linear economy with sharing goals to the CE model is unavoidable (Adams et al., 2017). The successful move to sustainable construction may be encouraged by CCE being implemented in the construction sector. Despite an early stage of growth in the building industry, CCE’s technological contribution in the building industry is rising significantly (Hossain et al., 2020). Moreover, the do-it-yourself methods emphasize the intentional use of digital technology to enhance consumer engagement and involvement in enterprises (Upadhyay et al., 2021a,b). The integration of various life cycle planning and development techniques for materials and grouch elements will provide a clear way to evaluate CCE’s efficiency at the project design level and decrease the difficulty of using CCE for the building environment to make it easier for the various organizations in the supply chain to understand (Benachio et al.,

2020). It will also help promote the alignment in the constructed environment of a more regularly accepted CCE concept, taking both short- and long-term priorities and benefits into account, fostering coordination among industry stakeholders in the diverse supply chains (Mao et al., 2018). Blockchain technology may aid the CE by lowering transaction costs, improving supply chain performance and interaction, ensuring human rights protection, improving health-care patient privacy and well-being, and lowering carbon emissions (Upadhyay et al., 2021c). Moreover, operational constraints in the multitier supply chain direct organizations’ attention toward addressing their supply chain environmental issues (Jæger et al., 2021). Jraisat et al. (2021) discovered focal actor interaction mechanisms at triad levels, and the establishment of their dyads capacities leads to long-term supply chain sustainability (Upadhyay, 2020). Integration and synchronization of green initiatives with operational improvement measures have been highlighted as key aspects in the development of a sustainable green supply chain (Kumar et al., 2019; White et al., 2019).

Codagnone and Martens (2016) provide a good conceptual framework to map the collaborative economy, where they classified sharing platforms into (1) for-profit environmentally responsible companies in the one miming, production and recycling, reusing, and after-using chain, (2) non-profit activities for “true free sharing”—Couchsurfing, BeWelcome, (3) business-to-consumer—B2C, and (4) peer-to-peer—P2P categories. Many P2P platforms are owned and operated by companies, but the main actors are citizens (e.g., Uber, Airbnb, and Upwork). Theories of sustainable behavior have studied a complex of motivation, environmentally oriented actions, and values that reduce the burden on the environment, based on the principles of the theory of rational choice and behaviorism (Koger and Winter, 2011). There are Theory of Planned Behavior (Ajzen, 1991), the Norms Activation theory, which provides for behavior change through the rational rethinking of constructive and deconstructive practices for nature as a personal benefit for the individual (Schwartz, 1977), and the value-belief-norm model, which explores the balance between “egocentric” and “biospherical” values (Stern, 2005). Authors of these theories proposed that people always have a choice between constructive (saving nature) and destructive actions. This choice is determined by the time and resource costs, the efforts that need to be made to take environmental actions, and the determining factor here is what people consider rational for themselves (i.e., the values of an economy of unlimited growth or a green economy values, which will be the basis for the actions taken) (Kollmuss and Agyeman, 2002). Summarizing the meta-studies, it is possible to say that the higher the level of convenience of the technological infrastructure and the greater the control by institutions, as well as the higher the level of an individual’s sense of personal responsibility for the actions performed, the more likely it is to practice ecological-sustainable practices and strengthened environmentally friendly norms of behavior are (Steg and Vlek, 2009; Chernovich, 2013). Mega-events act as an institution where it becomes possible to model from scratch a technologically convenient infrastructure that solves local social, environmental, and economic issues, creating new social and environmental practices throughout the



life cycle through a system of sanctions and rewards affecting streamlining the process, ensuring proper levels of “comfort” characteristic for different categories of citizens.

The priority of using the CCE models gives opportunities for expanding and extending the life cycle. Policies for a CE have the potential to incentivize and change the behavior of both consumers and companies toward CE goals. Such networks enable partnerships and interactions across the value chain, and they can also be catalysts for change. CCE approach promotes equality in the provision of services both for participants with high economic and cultural capital and for the most disadvantaged social groups (Petropoulos, 2016; Nußholz, 2017).

## Ecosystem Damage Assessment for Circular Economy Applications

Globally, habitats are at risk (Zink and Geyer, 2017; Onat et al., 2020; Al-Buenain et al., 2021). Damaged habitats are caused by the extinction of biodiversity within the environment, by degradation, and/or by the food web (Kutty et al., 2020b). Due to all animals living in dynamic, interdependent environments, removing or modifying one species or abiotic factors hold detrimental effects within the environment and for others (Murray et al., 2017). Industry requests for guidance in adopting sustainable growth policies have long been made (Park et al., 2010; Elhmoud and Kutty, 2021). The triple bottom line method prioritizes operational improvement, decreases greenhouse gas emissions, and enhances the social welfare of the general public (Laing et al., 2019). The CE is the latest effort to comprehend sustainable convergence between economic development and environmental well-being (Geng and Doberstein, 2008; Nuñez-Cacho et al., 2018). Digitalization might be extremely beneficial in the development of circular products that are both sustainable and circular. Furthermore, customers must be involved in the development of new, sustainable circular goods utilizing digitalization (Agrawal et al., 2021).

Determination of damage is a preliminary on-site measurement of an accident or natural disaster damage or failure. Damage evaluations document the extent, repair, reconstruction, or recovery of damage. The time taken for maintenance, replacement, and regeneration can also be measured (Itsubo et al., 2004). Human beings deliberately and unexpectedly change habitats and, consequently, impact human well-being [Sustainable Development Goals (SDG) 3] on the size of the environment. There is growing consensus that interventions (a) connect human behavior with probable changes in the environments and (b) link changes to consequent changes in human well-being are required for informed environmental management and policy (Ghisellini et al., 2016). Although the CE stresses the renovation of systems and resource cycling that can help make business models more competitive, it also encompasses the conflicts and boundaries (Huysveld et al., 2019). The CE opposes the produce–use–dispose paradigm and encourages resource reuse (Upadhyay et al., 2021d). This involves the lack of a social component, which restricts the ethical dimension and specific unforeseen implications of sustainable development (Saldarriaga-Hernandez et al., 2020).

Social components, including social health (physical and psychological), depending on the environmental and economic conditions, the predominated balance of constructive sustainable social practices, values, and attitudes that save the environment and deconstructive in local society, determined quality of life and level of well-being. Well-being (expressed by the human development index of a country) levels off at a certain level of resource use (expressed by the material footprint of the country), showing that from a certain high level of well-being, additional resource consumption no longer improves the level of well-being, but the quality of the environment, solidarity, and safety made a contribution for the wellness and health (Tukker et al., 2014).

Evolutionary theories explain the desire for richness, a distinctive genetic program of behavior for human communities due to mining, accumulating, producing, and consuming necessary materials for societal survival. However, the societies whose values are based on the balanced cooperative values and lean production, services, carrying out sharing practices and benefits, creating a network of communications, developed faster in long-term wellness and richness perspective in comparing with societies that were built only on the values of growth, i.e., the accumulation of wealth and the consumption of resources. In other words, the higher the quality of CCE practices (environmental friendliness and sharing values), the higher the resource efficiency of the economy, and a lower burden on the environment, ecosystems are more resilient, the carrying capacity of the environment is higher, environmental crises are overcome faster, and less the level of social inequality (Buss, 2019). CCE helps secure global resource availability in recognizing values of the social well-being, preserve the ability of natural systems to deliver goods and services to society, create new green developing stimulus and technologies, new norms and institutions, encourages redesigning of policy and regulation, generate CCE value to society directly *via* stimulation of employment and benefits associated with boosting of the recovery, recycling and upgrading of valuable materials; creating new business models and eco-design systems that facilitate circularity, further developing clean and sustainable raw materials extraction and upgrading processes required to underpin healthy social systems (Jackson, 2009). This contributes to a modern concept of the CE as a monetary system that designs and manages both mechanism and performance to optimize ecological integrity and social health, such as scheduling, resources, sourcing, development, and reuse (Genovese et al., 2017).

The latest usage of energy and low-carbon development policies, which involve the introduction of the CE model, is motivated by challenges to balance industrial innovations, environmental and human health, and economic growth in China and elsewhere in the world (Prieto-Sandoval et al., 2018). A core topic of the CE principle is the determination of resources within a locked framework to ensure the use of natural resources while mitigating emissions or preventing limits on resources and maintaining economic development (Jun and Xiang, 2011; Sauv   et al., 2016). For example, to evaluate the effect of the Deepwater Horizon oil spillage on ecological resources, it is essential to

determine how the ecosystem transition has occurred in the accident and how these changes have contributed to changes in ecosystem services provision and benefit (Atiku, 2020). To calculate such shifts, the disparity in ecosystem resource provision and value with vs. without must be calculated (Nakano et al., 2007). Moreover, circular practices support sustainability by helping businesses get the most out of limited resources and achieve zero waste goals. Better customer experience may also be obtained through service innovation that has a lower environmental effect (Upadhyay et al., 2019, 2020).

Secondly, how do improvements in ecological form and composition result in ecosystem service provision changes? The “ecological production functions,” as defined by the composition and operation of ecosystems, are used to characterize the provision of ecosystem services (Errington et al., 2018; Morseletto, 2020; Spanos et al., 2021). They can be used as a “transfer function” or model indicative of ecological dynamics to achieve an impact on ecosystem resources through ecosystem changes in ecosystem conditions (e.g., habitat loss and shrimp fishery yields). Environmental output functions could be used to forecast the evolving ecosystem structure and functioning of the distribution of different ecosystem services for all stakeholders participating in the economic system (Robertson et al., 2007; Winans et al., 2017).

## State-of-the-Art and Objectives

Qatar’s obligation to deliver FIFA World Cup™ 2022 as a carbon-neutral event has set standards for environmental leadership by managing the existing water and waste management practices, applying sustainable building standards, and implementing solutions with low CO<sub>2</sub> emissions. Reducing an ecological burden from the carbon-gushing games requires CCE strategies that give way to new thinking on environmental effectiveness and economic efficiency to sustain legacy in global sports. To determine the environmental effect of a commodity in various ways, the LCA requires comprehensive techniques (Sleeswijk et al., 2008) to quantify impacts across various protected areas. There is a need for approaches to easily produce understandable and easy-to-understand outcomes for regular decisions in better understanding the impacts from a broader viewpoint. In light of the environmental problems posed by the consumer community, the study uses the ReciPe LCIA model, built as a method for resolving the burden inflicted on specific areas of protection. The ReciPe method is best regarded for its vast coverage of impact category indicators when compared with different methods such as EPS 2000, IMPACT (2002+), and Eco-indicator (99). This study is the first of its kind to understand the impact of modular stadium construction on the ecosystem from a life cycle perspective using the ReciPe method.

To continue, an issue associated with inventory items in LCA is the synergistic nature of some compounds. The synergistic effect of mixed compounds may increase the concern about the original compound or create a new compound(s) that is not captured in the inventory. Such synergistic compounds may have the potential to create combined impacts greater than those of the individual releases. This study ignores the synergistic compounds in the inventory, but due concern is given in recognizing the

potential effects and other factors (e.g., antagonistic effects and assimilative capacity) when drawing conclusions based on the results of the ecological life cycle assessment conducted in the study. In addition, the fundamental terms used in ecological impact assessment arise confusions; for example, distinguishing between an inventory item and an impact is not always easy. Although the common practice is to account for the amount of solid waste materials produced by a system in inventory analysis, it is not common to account for the amount of natural habitat consumed to dispose of that solid waste. Accounting to a CE strategy, the amount of construction waste materials is considered as an input under the cradle-to-cradle assumption, while also classified as an impact on the ecosystem. Furthermore, most studies to date have just conducted life cycle assessments with supporting policy recommendations when it comes to understanding the impacts of green design infrastructures on the environment. None has yet focused on bringing CCE as a potential leverage source to minimize the impact on the ecosystem. This study brings out a perspective analysis from a CCE strategy for sustainable construction practices for World Cup mega-events to lessen the burden on the ecosystem. Despite best efforts, to green, the FIFA World Cup is challenging and requires critical analysis on possible burdens and leverage points to leave a long-lasting legacy. To this end, this paper aims to achieve the following objectives, namely:

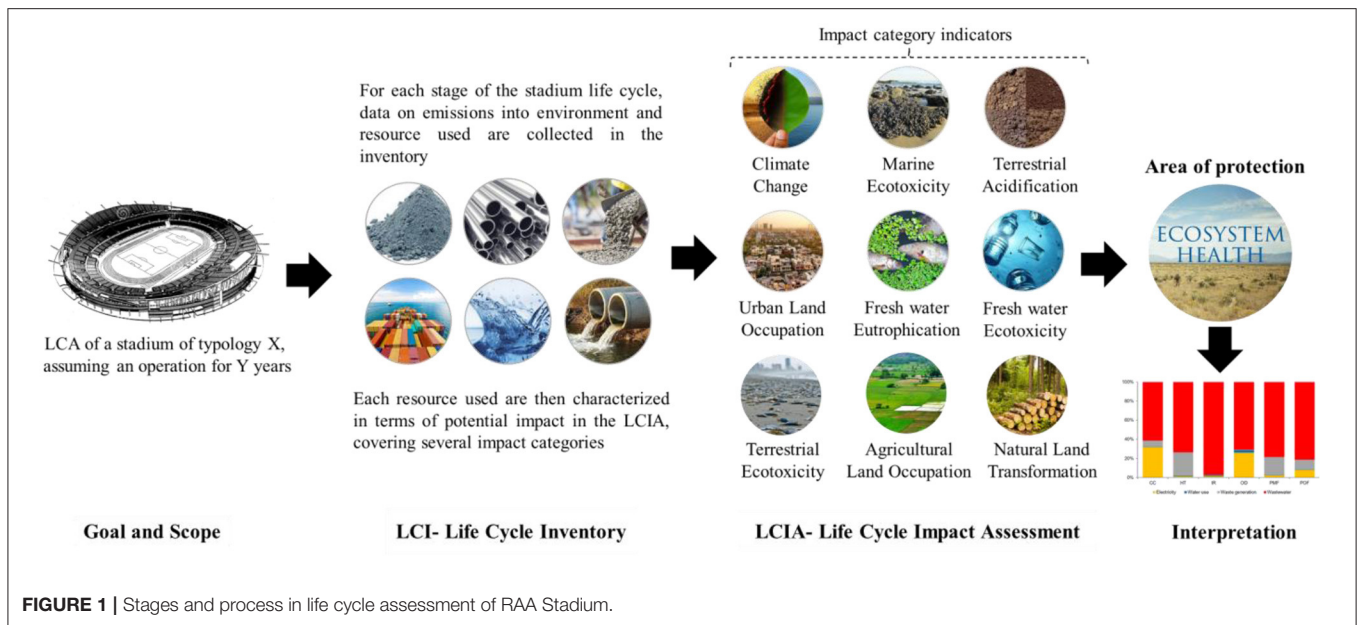
- a) Conduct a “cradle-to-cradle” life cycle assessment to quantify the midpoint environmental and endpoint ecosystem damage for the case of sustainable modular stadium designs using the ReciPe method considering the RAA Stadium as a case study.
- b) Identify the most influencing impact category that inflicts possible damage to the ecosystem across each life cycle phase along with the material/activity that holds a significant impact across each impact indicator and the life cycle stage that inflicts most damage to the ecological diversity.
- c) Investigate the extent of impact per category indicator subject to material quantity variations using a simulation-based sensitivity analysis.
- d) Carry out a perspective analysis on how a circular collaborative economy can reduce possible ecological burdens before, during, and post-World Cup with possible alternative recommendations and strategies to achieve sustainable development.

## RESEARCH METHOD

### Method

The study adopts the conceptual framework developed by the United Nations Environment Programme (UNEP) and the Society of Environmental Toxicology and Chemistry guidelines for environmental life cycle assessment (E-LCA) to quantify the endpoint ecological quality for sustainable modular stadium designs taking the case of the RAA Stadium in the State of Qatar. The three-phase conceptual framework contains the following activities, namely:

1. Classification: the process of assignment and initial aggregation of life cycle inventory data to relatively



homogeneous groupings of impacts (e.g., photochemical smog, lung disease, and fossil fuel depletion) within primary impact categories (e.g., ecosystem, human health, and natural resources).

2. Characterization: the qualitative and/or quantitative evaluation of potential impacts. The process of identifying impacts of concern (called assessment endpoints) and selecting actual or surrogate characteristics (called measurement endpoints) to describe the characterization of the impact involves using specific impact assessment models to develop impact descriptors.
3. Valuation: The explicit and collective process of assigning relative values and/or weights to impacts using informal or formal valuation methods.

The entire study process can be seen from the research flow diagram in **Figure 1**. Here, the first phase begins by identifying the goal and scope of the assessment and indicating the system boundaries and functional unit; the second phase is the life cycle inventory analysis, which involves data collection; the third phase is the LCIA, in which both the midpoint impact category indicators and the endpoint area of protection are selected; finally, the fourth phase covers the analysis and interpretation of results from the LCIA outputs.

### Ras Abu About Stadium: A Case Study

The RAA Stadium is the first of its kind sustainable modular stadium design in the World Cup history to host the 2022 carbon-neutral FIFA World Cup in Qatar's oil-rich state. Located on the waterfronts of West Bay with a seating capacity of 40,000, the RAA Stadium uses shipping containers and removable seats as modular blocks for construction that can be repurposed and dismantled after the mega-sporting event. These parts are intended to be used in community facilities such as hospitals and other projects, whether sports-related or not, both locally

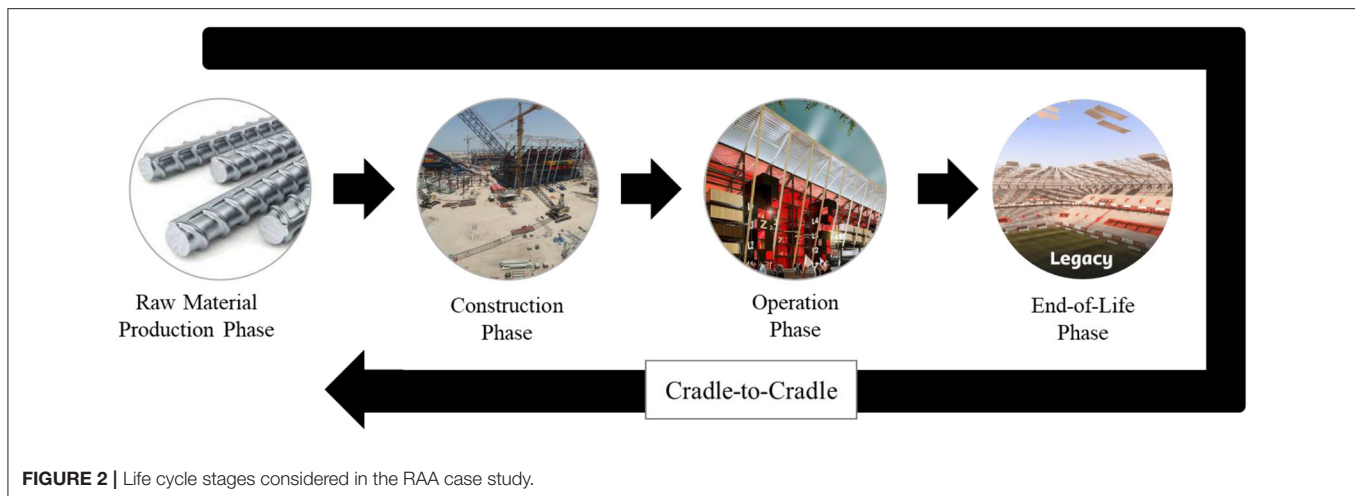
and abroad. From a sustainability perspective, the modular and prefabricated elements used in construction will seek to reduce the waste generated, carbon emissions, and the total amount of materials necessary for construction. Moreover, with the reuse of the seats, roof, and other parts of the stadium in developing countries, a positive legacy for Qatar will be established for years and even decades to come (FIFA, 2020).

### System Boundary and Functional Unit

The study adopts a “cradle-to-cradle” E-LCA to quantify the associated endpoint ecosystem damage across each impact category. Four life cycle phases were included in the study, namely, (a) raw material production phase, (b) construction phase, (c) operations phase, and (d) EOL phase. The first phase involves the manufacturing and production of construction materials, pipeline systems, openings, and finishing materials. This phase also involves the burden avoided by the recycled materials, which were used in the production process of several materials. The construction phase covers the total diesel consumed by heavy equipment and during the transportation processes of materials to the site and the freight transport of shipping containers through waterways.

Furthermore, the consumed electrical energy, the consumed water, solid wastes, and wastewater generation were covered in both the construction and the operation phases, knowing that the specified unit processes in the operation phase shown in **Figure 2** were determined on an annual basis. Because the RAA Stadium is the first fully demountable stadium in the World Cup history, the EOL phase will cover some circularity and sharing economy scenarios for the reuse, repurpose, recycling, and refabrication of the stadium's components other purposes. The study considers the entire stadium area of 450,000 square-meter as the functional unit.





## Inventory Data of Life Cycle

According to the requirement of the international standards, ISO 14.040 (International Organization for Standardization, 2006a) and ISO 14.044 (International Organization for Standardization, 2006b) series, the LCIA second phase in the LCA methodology, which contains the understanding and quantification of all physical energy and materials, flows input and output of the system. The actual data for the RAA Stadium for all the stages of the life cycle were obtained from the World Cup local organizing committee: Supreme Committee of Delivery and Legacy, State of Qatar. Life cycle inventory data are represented in **Table 2**. In the material production phase, the material quantities are measured in kilograms and are categorized into recycled and virgin (non-recycled) raw material amounts. Furthermore, the construction phase includes the data for energy consumption of electricity and water, fuel utilization, freight transportation, and waste generated. As for the operation phase, it is important to note that because the RAA Stadium is currently under construction, the operational data were estimated by the Supreme Committee based on the operation of Al-Janoub Stadium, Doha-Qatar, a stadium with a seating capacity of 40,000, equal to that of the RAA Stadium.

## Life Cycle Impact Assessment

The LCIA transforms “stock” sources into simplified metrics. The study uses the ReCiPe 2008 impact assessment model for the endpoint area of protection “ecosystem quality (EQ).” The primary purpose of the ReCiPe process is to render a small number of predictor outcomes of the long list of life cycle inventories (Zanghelini et al., 2016). These metrics display the relative magnitude of a type of environmental effect. The endpoint impact assessment covers all the category indicators along the “cause-effect” chain from the LCI results to the respective area of protection (Park et al., 2016). The endpoint categories are divided into three groups based on their effect or damage inflicted on human health (HH), ecosystem diversity (ED), and resource availability (RA). The preliminary framework to characterize the measurement endpoints of specific

inventory items to impacts was identified under the tier 5 type characterization model proposed in the 1992 SETAC Life-Cycle Impact analysis guide (see SETAC, 1993). Here, the site-specific ecological or human health-related information of the RAA Stadium is used to estimate the potential impacts of the inventory items. This study considers nine midpoint environmental impact category indicators, which are further converted into the endpoint area of protection: ecosystem diversity. The midpoint impact categories include climate change (CC), marine ecotoxicity (ME), terrestrial acidification (TA), urban land occupation (ULO), freshwater eutrophication (FEU), freshwater ecotoxicity (FET), terrestrial ecotoxicity (TE), agricultural land occupation (ALO), and natural land transformation (NLT).

The next stage in the LCA is to convert the LCI results to the ecosystem impact category so as to identify the possible impact on ecological quality. The life cycle impact assessment database Ecoinvent v3.7.1 developed by the Swiss Center was used for the analysis. The database offers LCI data covering building materials, renewable fibers, metals, chemicals, and energy (e.g., solar heat, wind power, and electricity) (Frischknecht et al., 2007). The study uses the ReCiPe midpoint (E, A) method, where the midpoint characterization factors are converted to the endpoint characterization factor using conversion factors obtained from the ReCiPe 2008 handbook on LCIA (Goedkoop et al., 2008). In ReCiPe, each method (midpoint and endpoint) contains factors according to the three cultural perspectives. These perspectives, namely individualist (I), hierarchist (H), and egalitarian (E), represent a set of choices on issues such as time or expectations that proper management or future technology development can avoid future damages. The study uses the egalitarian cultural perspective, a long-term based on precautionary principle thinking, here the CCE thinking principle as a sustainable long-term solution to avoid damage.

The calculations to quantify the endpoint impact damage on ecological quality through an E-LCIA is as follows:

- a) Choose the midpoint characterization factor ( $CF_m$ ) for each environmental impact category under the ReCiPe midpoint



**TABLE 2 |** Life cycle inventory data of Ras Abu About Stadium.

Materials/activities	Category	Virgin amount	Recycled amount	Unit used
<b>Raw material phase</b>				
Concrete	Concrete	2.41E+08	6.97E+06	kg
Earthworks	Fill	0.00E+00	3.69E+05	kg
Base plaster	Finishes	2.51E+05		kg
Ceramic tiles	Finishes	1.80E+04		kg
Epoxy resin	Finishes	3.59E+05		kg
Gypsum board	Finishes	1.33E+06		kg
Nylon product	Finishes	2.69E+05		kg
Paint	Finishes	5.61E+04		kg
Polypropylene fabric	Finishes	2.04E+05		kg
Stone plate	Finishes	2.58E+05		kg
Vinyl floor	Finishes	8.78E+04		kg
Coatings to steelwork	Finishes	1.94E+07		kg
Intumescent fire protection	Finishes	8.41E+05		kg
Containers stairs	Finishes	1.28E+07		kg
Average metal pipe product	Metals	8.67E+05		kg
Steel	Metals	3.91E+07	1.24E+07	kg
Average metal product	Metals	6.60E+07		kg
Glass	Openings	1.19E+06	1.80E+05	kg
Wood door	Openings	1.01E+05		kg
Mineral pipe insulation	Other	1.58E+06		kg
Plastic and metal	Other	5.72E+04		kg
Polyethylene foam	Other	6.27E+04		kg
Pitch	Other	2.05E+06		kg
PVC thermoplastic sheet	Thermal and Moisture	1.80E+06	2.17E+05	kg
<b>Construction phase</b>				
Diesel		6.92E+05		kg
Total electricity consumption		8.94E+06		kWh
Water use		6.37E+04		m <sup>3</sup>
Freight		6.87E+08		tkm
Waste generation		8.26E+08		kg
Wastewater		2.23E+04		m <sup>3</sup>
<b>Operation phase</b>				
Electricity and cooling total		4.38E+06		kWh
Water use		1.90E+04		m <sup>3</sup>
Waste generation		1.75E+03		tons
Wastewater		8.64E+03		m <sup>3</sup>
<b>End-of-life phase</b>				
Average metal product	Finishes	1.03E+06		kg
Concrete	Concrete	2.41E+08		kg
Steel	Metals	3.65E+07		kg
Ceramic tiles	Finishes	1.80E+04		kg

(E, A) from the Ecoinvent v3.7.1 LCIA database for the selected activity.

- b) Calculate the midpoint impact across each impact category ( $M_{i,a,x}$ ) for quantity (Q) under each activity in the life cycle

stage according to Equation 1

$$M_{i,a,x} = CF_m \times Q \tag{1}$$

where,

$M_{i,a,x}$  = the midpoint impact of  $i^{th}$  impact indicator under the area of protection “a” using the uncertainty perspective “x.” Here, a and x represent ecosystem damage as the area of protection and egalitarian as the uncertainty perspective, respectively.

- c) Evaluate the endpoint damage on the ecosystem across each impact category for Q quantity using the appropriate conversion factor (F) according to Equation 2

$$E_{i,a,x} = M_{i,a,x} \times F_{M \rightarrow E} \tag{2}$$

where,

$E_{i,a,x}$  = endpoint impact of the  $i^{th}$  impact indicator under the area of protection “a” using the uncertainty perspective “x.”

$F_{M \rightarrow E}$  = midpoint to endpoint conversion factor obtained from ReciPe 2008 handbook on LCIA. **Table 3** shows the ReCipe impact category indicators, conversion factors (from midpoint to endpoint), and units of conversion used in this study.

- d) Calculate the overall endpoint damage across each life cycle stage following Equation 3

$$E'_{j,a,x} = \sum_{i=1}^n E_{i,a,x} (n = 9) \tag{3}$$

where,

$E'_{j,a,x}$  = endpoint impact of the  $j^{th}$  life cycle phase under the area of protection “a” using the uncertainty perspective “x.”

n = number of environmental impact categories considered in the study.

## RESULTS AND DISCUSSION

### Ecosystem Damage Assessment: A Life Cycle Approach

To find the ecosystem damage (in species.year) for sustainable modular stadiums taking the case of the RAA Stadium in Qatar, nine endpoint impact categories as stated in *Life cycle impact assessment* were assessed. These categories were studied through the stadium’s life cycle stages: production, construction, operation, and EOL to identify the most influential life cycle stage and material/activity and to help drive conclusions and policy recommendations and highlight areas of improvement for reduced ecological impacts to the environment. Two scenarios were adopted for the life cycle analysis, enabling the comparison of possible savings in operations. Scenario 1 considers a circular approach with a single year of operation, after which the stadium would be dismantled post-FIFA 2022. Scenario 2 considers the standard approach with a 30-year operation, assuming that the

**TABLE 3** | ReCipe impact category indicators, conversion factors, and units of conversion used in this study.

Environmental impact category	Unit of CF <sub>m</sub>	Midpoint to endpoint conversion factor	Unit of CF <sub>e</sub>	Unit
Agricultural land occupation	m <sup>2</sup> yr	1.1E-10	Species.yr/m <sup>2</sup> yr	Speciee.years
Climate change, ecosystems	kg CO <sub>2</sub> -eq	2.5E-0.8	Species.yr/kg CO <sub>2</sub> -eq	
Freshwater ecotoxicity	kg 1,4-DCB-Eq	7.0E-10	Species.yr/kg 1,4-DCB-Eq	
Freshwater eutrophication	kg P-Eq	6.1E-07	Species.yr/kg P-Eq	
Marine ecotoxicity	kg 1,4-DCB-Eq	1.1E-10	Species.yr/kg 1,4-DCB-Eq	
Natural land transformation	m <sup>2</sup>	6.8E-13	Species.yr/m <sup>2</sup>	
Terrestrial acidification	kg SO <sub>2</sub> -Eq	2.1E-07	Species.yr /kg SO <sub>2</sub> -Eq	
Terrestrial ecotoxicity	kg 1,4-DCB-Eq	5.4E-08	Species.yr/kg 1,4-DCB-Eq	
Urban land occupation	m <sup>2</sup> a	8.9E-09	Species.yr/m <sup>2</sup> a	

CF<sub>m</sub>, midpoint characterization factor; CF<sub>e</sub>, endpoint characterization factor.

RAA Stadium will remain for a life span of 30 years before decommissioning (Frawley and Adair, 2013).

Scenario 1 analysis revealed that the production phase is the most dominant, contributing 99.99% across all life cycle phases. This domination can be linked to the negative environmental impact of certain materials used within the stadium construction; detailed impact analysis for the materials used within RAA stadium will be investigated in the next section. Additionally, **Figure 3A** shows that CC and ME dominate all impacts categories across all the life cycle phases with a contribution ranging from 80 to 95%. The possible reasons could be due to greenhouse gas (GHG) emissions contributing to the CC impact category and possible acid rain, as ME is well related to the GHG emissions, or due to dumping harmful chemicals at the waterfronts during the life cycle.

On the other hand, Scenario 2 analysis revealed the dominance of both production and operation phases with the following comparative combinations of 99.78:0.21, 62.31:37.69, 46.63:53.40, 65.20:34.80, 27.04:72.96, 99.06:0.94, 82.04:17.96, 0.73:99.30, and 97.68:2.31% corresponding to the following impact categories ALO, CC, FET, FEU, ME, NLT, TA, TE, and ULO, respectively. The project's planned circularity contributed to saving at the EOL that reached more than  $4.26 \times 10^7$  species.year compared with 1.7 species.year for the overall life cycle with a considerable burden avoided across the CC and ME impact categories, as shown in **Figure 3A**.

Additionally, using recycled materials within the stadium construction materials avoided more than 50% of the environmental burden across the overall impact categories (**Figure 3B**), which emphasizes the positive influence of using recycled materials during construction on the stadium's overall construction cost and the environment.

Further investigation conducted for the materials influencing each impact category across each life cycle phase revealed that concrete is the most influential material across the nine endpoint ecological impact categories, with a contribution ranging from 98.67 to 99.95%. Moreover, concrete has the highest avoided burden among all materials, as shown in **Figure 4A**. The remaining materials have a minor influence, and only the average metal product is significant among all the remaining 34 materials, contributing within a range from 0.02 to 1.26%.

On the other hand, the two primary causative activities among the impact categories are freight and waste generation in the

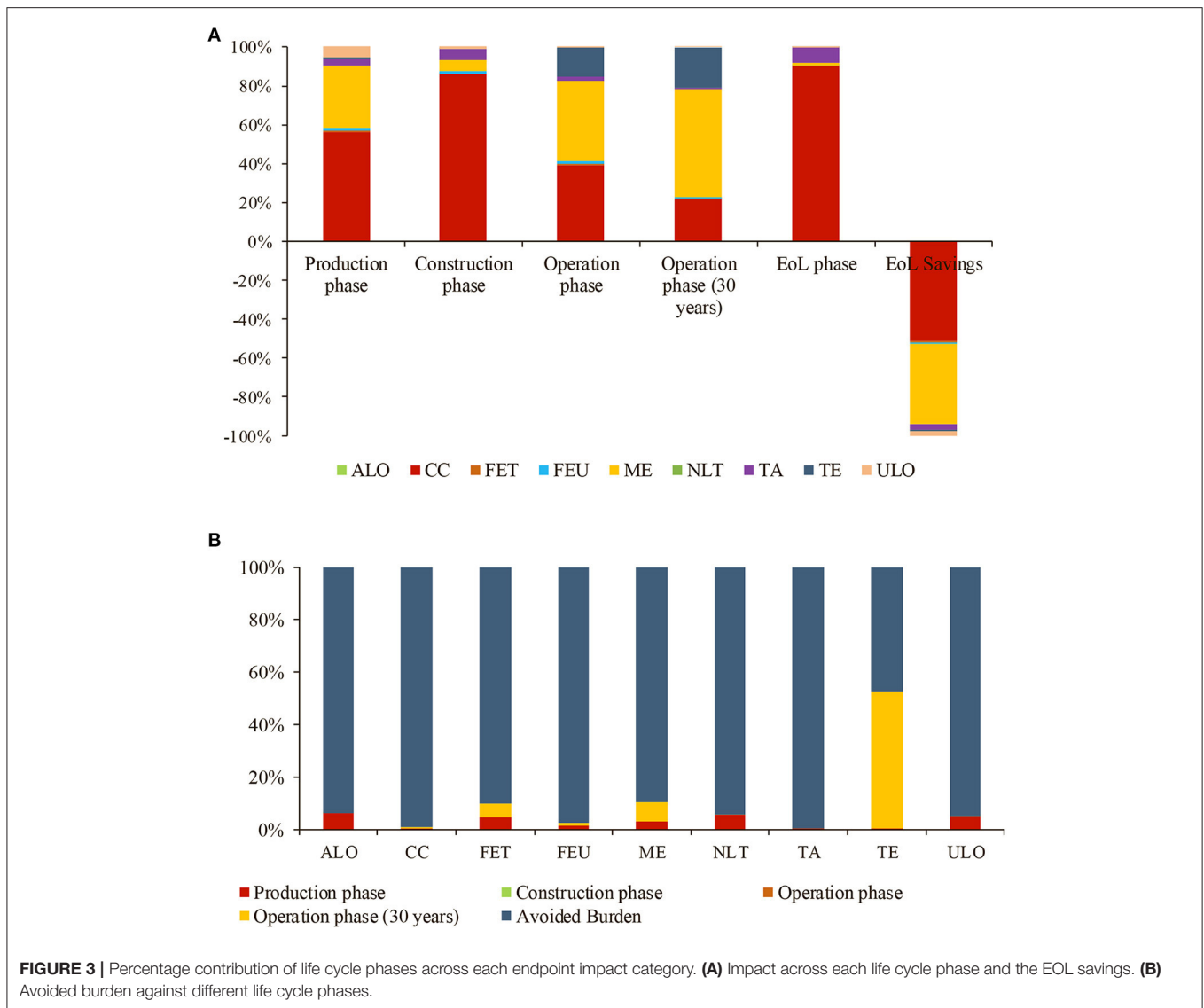
construction phase, as shown in **Figure 4B**. Freight contributes significantly across the CC impact category with an endpoint value of  $7.97 \times 10^{-1}$  species.year and a contribution of 76.22%. GHG emissions play a role in impacting CC due to the standard shipping methods that rely on non-renewable energy sources, as most of the construction materials are imported from outside the State of Qatar. Freight's influence on FET and TA ranges between 15.17 and 87.60%, respectively. The second-ranked influencer for the construction phase is the waste generation with a value of  $1.28 \times 10^{-1}$  species.year for CC (12.26%); due to the lack of a complete recycling process for all the construction waste, most of the construction waste ends up in landfills. Waste generation contributes ~15.17 and 87.60% for FET and TA, respectively. The remaining activities hold a negligible impact of <1%.

Furthermore, all the activities contribute differently across each impact category for the operation phase. The activities contributing across each impact category is as follows: "water used" across ALO (with a contribution of 66.29%), waste generation impacting CC, FET, FEU, ME, TA, TE, and ULO (with contributions of 90.35, 99.73, 93.97, 99.78, 74.74, 99.97, and 88.50%, respectively), and "electricity and cooling" impacting NLT (with a contribution of 53.57%), as shown in **Figure 4C**. However, the highest value of impact was for the "waste generation" across the CC impact category with a value of  $1.17 \times 10^{-2}$  species.year; the reasons match the one's highlighted in the operation phase.

Finally, in the EOL phase, we focus on net savings. The dominating material is again concrete with a significant saving across CC, for a value of  $2.06 \times 10^7$  species.year. The savings range from a value of 98.67 to 99.95% for NLT and FET, respectively. The most savings were for the impact category CC, 51 to 84% for concrete and steel, followed by the impact category ME with a range of saving from 8 to 41% for steel and concrete, as indicated in **Figure 4D**. These substantial EOL savings are due to possible reuse/recycle strategies instead of completely using the virgin concrete structures.

## Sensitivity Analysis

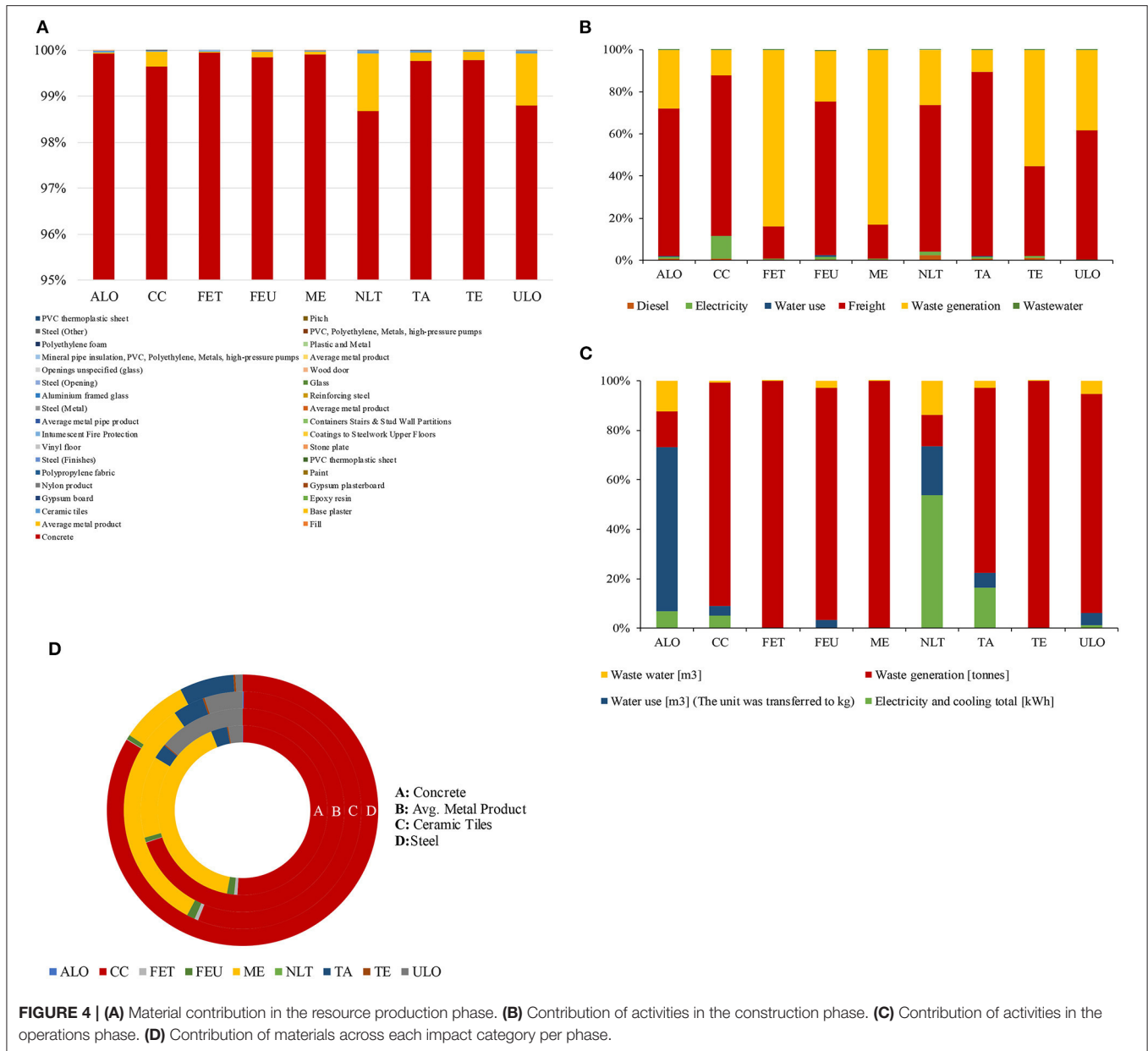
The level of sensitivity for each environmental indicator across all the life cycle stages subject to possible variations in the quantity of the material used was identified through a sensitivity



analysis. Tableau v2021.1 software was used to conduct the sensitivity study. Under a probabilistic scenario, each material quantity across the respective life cycle stage that contributed significantly to the ecosystem damage endpoint was chosen as the sensitivity analysis's input parameters. In the production phase, the respective quantities for concrete, average metal product, ceramic tiles, and steel were subject to a simultaneous increase (+) or decreased (-) in quantities by  $\pm 10$ ,  $\pm 30$ , and  $\pm 50\%$ . All the other material quantities were kept constant due to their negligible contribution to the ecosystem damage endpoint as identified through the LCIA analysis. Varying these materials will not bring any significant change in the sensitivity study and may even bias the analysis results. A tornado chart shows the impact of the set input parameters on the response variables. The bars in the tornado chart show the change in the response variable (environmental impact category). The impact category

at the top has the biggest effect on the response variable, whereas the one at the bottom has the least effect. Results showing the sensitivity of each environmental impact category to changes in the quantity of materials in the material production phase can be seen in **Table 4**. The sensitivity analysis results (see **Figure 5**) reveal CC as the impact category most sensitive to changes in material quantities in the raw material production phase. ME is the second most sensitive impact category followed by TA, ULO, FEU, FET, TE, ALO, and NLT as the least sensitive environmental impact category to possible volumetric changes in quantity.

The sensitivity analysis results across the construction and operation stages for each impact category to changes in the material quantity as depicted in **Tables 5, 6**, respectively. In the construction phase, freight (tkm) and waste (kg) were subject to quantitative changes by  $\pm 10$ ,  $\pm 30$ , and  $\pm 50\%$ . The other materials were kept constant. It was observed that CC is

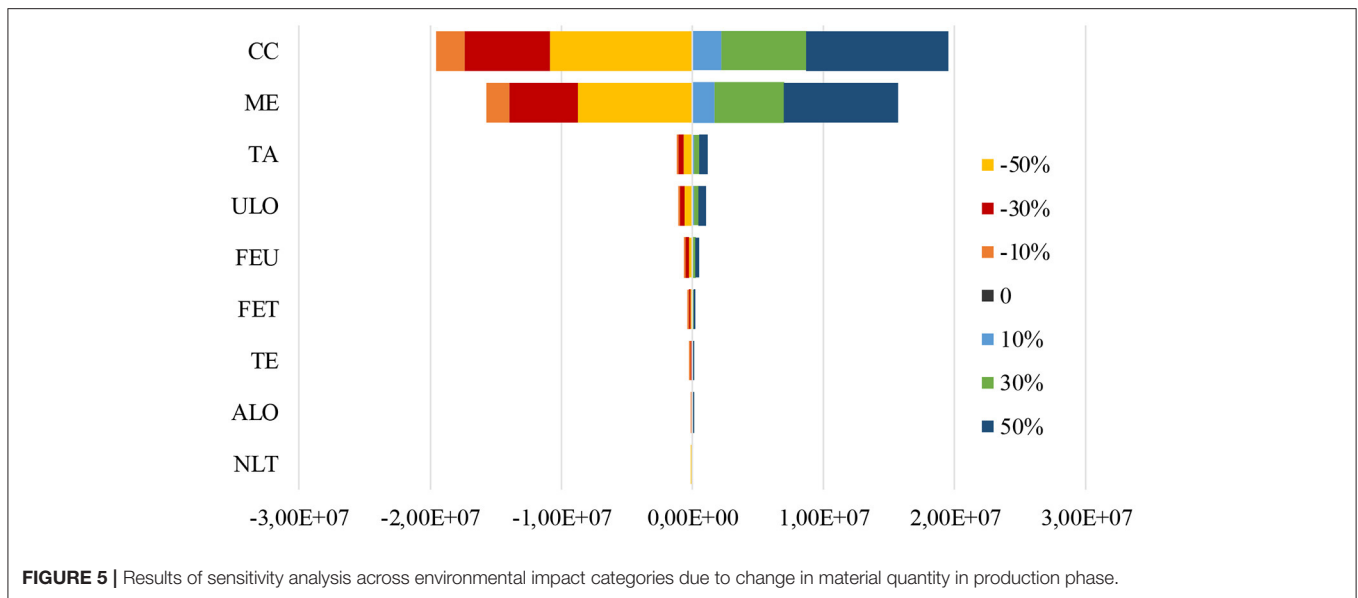


**FIGURE 4 | (A)** Material contribution in the resource production phase. **(B)** Contribution of activities in the construction phase. **(C)** Contribution of activities in the operations phase. **(D)** Contribution of materials across each impact category per phase.

**TABLE 4 |** Sensitivity analysis results for quantitative variations across each endpoint impact category for production phase (in species.yr).

Impact categories	-50%	-30%	-10%	0	10%	30%	50%
Agricultural land occupation	2.03E+04	2.84E+04	3.66E+04	4.06E+04	4.47E+04	5.28E+04	6.09E+04
Climate change, ecosystem	1.08E+07	1.52E+07	1.95E+07	2.17E+07	2.39E+07	2.82E+07	3.25E+07
Freshwater ecotoxicity	1.31E+05	1.84E+05	2.36E+05	2.62E+05	2.89E+05	3.41E+05	3.94E+05
Freshwater eutrophication	2.92E+05	4.09E+05	5.25E+05	5.84E+05	6.42E+05	7.59E+05	8.75E+05
Marine ecotoxicity	8.72E+06	1.22E+07	1.57E+07	1.74E+07	1.92E+07	2.27E+07	2.62E+07
Natural land transformation	3.18E-01	4.45E-01	5.73E-01	6.36E-01	7.00E-01	8.27E-01	9.54E-01
Terrestrial acidification	6.56E+05	9.18E+05	1.18E+06	1.31E+06	1.44E+06	1.70E+06	1.97E+06
Terrestrial ecotoxicity	4.99E+04	6.99E+04	8.99E+04	9.99E+04	1.10E+05	1.30E+05	1.50E+05
Urban land occupation	5.84E+05	8.18E+05	1.05E+06	1.17E+06	1.29E+06	1.52E+06	1.75E+06





most sensitive to volumetric changes in the construction phase (Figure 6). The second most sensitive impact group inflicting damage to the ecosystem quality with possible changes in material quantity in the construction phase is the ME, followed by TA, ULO, FEU, FET, TE, ALO, and NLT (in decreasing order of sensitivity). When considering the operations phase, climate change is still the most sensitive impact category subject to quantitative variations followed by natural land transformation, marine ecotoxicity, terrestrial ecotoxicity, terrestrial acidification, freshwater eutrophication, urban land occupation and freshwater ecotoxicity, and agricultural land occupation. In this phase, the analysis was carried out by varying electricity and cooling (kWh) and waste generation (tons) quantities while keeping other inventory items constant. As explained earlier, these elements resulted in inflicting significant damage to the ecosystem endpoint across each impact category, as observed from the LCIA. Results of sensitivity analysis across environmental impact categories due to change in item volume in the operations phase can be seen from the tornado diagram in Figure 7.

## Rethinking Ecological Quality Through CCE: A Perspective Analysis

An EOL management from a CCE perspective besides the waste treatment alternative as argued in *Ecosystem damage assessment: a life cycle approach* is analyzed considering before, during, and post-event scenarios. Facilitating the football pitches laid out in the stadiums of Qatar as training grounds for various football associations in parts of Asia and the Middle East can help enhance the sportive spirit partnership (SDG: 17) goals of Qatar, a shift toward sharing economy goals. Such readily available training grounds can help many football nations to take advantage of the existing infrastructures to power up their level of excellence in football. Subtropical humid climates often hold

a negative impact on sporting events. Countries such as India and China, which have magnificent infrastructures in place for mega-events, often face difficulty scrolling up the list of host cities during bids due to their adverse humid climate, which can bring overheating concerns to the players. Transferring the innovative temperature control technology used in the FIFA 2022 World Cup™ stadiums to various such national league member states in Asia-pacific and Africa can help improve players' performance and the game as a whole. This supports the United Nations global technology transfer initiative and strengthens the transboundary partnership goals of UN SDGs (SDG: 17).

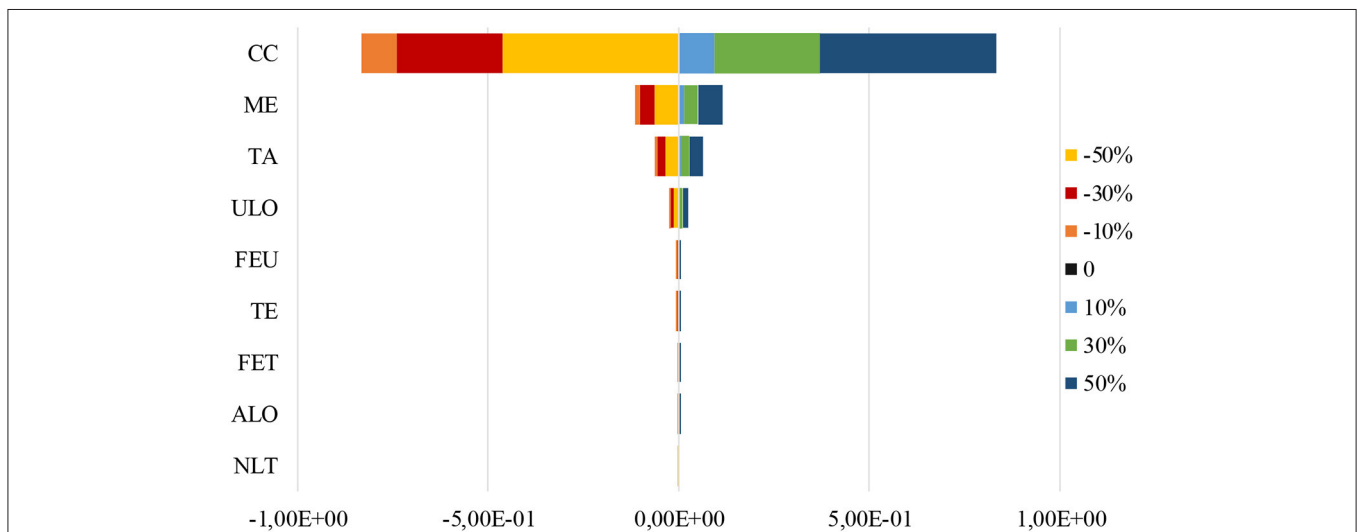
Reusing shipping containers reduces the burden on the environment, with a considerable reduction of 29% in CO<sub>2</sub> when shared and circulated within the economy (Gilbert et al., 2017; Kucukvar et al., 2021). This concept falls under the umbrella term CCE. For instance, repurposing shipping containers to "container gardens and greenhouses" helps in balancing the emissions generated during the event (SDG: 13) with reducing the cost and materials involved in constructing new greenhouse structures (SDG: 12). This ensures proper utilization of resources through sharing practices. A similar approach can be utilized by repurposing, refurbishing, and recycling the used shipping containers to bring circularity and sharing economy practices into action to maintain post-event legacy and sustainability. Further applications of shipping containers post-event mapped with corresponding SDGs is presented in Figure 8. As in many sports events, preventive actions to reduce waste and waste controlling and measuring play a significant role as a sustainability advantage (Rajan and Booth, 2016; Kutty and Abdalla, 2020). Atcharyasopon (2017) concluded that <15% of waste generated during sporting events made it to the recycling process. The rest of the commingled solid waste went to landfills and generated unnecessary GHG emissions. Therefore,

**TABLE 5 |** Sensitivity analysis results for quantitative variations across each endpoint impact category for construction phase (in species.yr).

Impact categories	-50%	-30%	-10%	0	10%	30%	50%
Agricultural land occupation	2.61E-05	3.62E-05	4.63E-05	5.13E-05	5.63E-05	6.64E-05	7.64E-05
Climate change, ecosystem	5.83E-01	7.68E-01	9.53E-01	1.05E+00	1.14E+00	1.32E+00	1.51E+00
Freshwater ecotoxicity	4.84E-04	6.74E-04	8.64E-04	9.60E-04	1.05E-03	1.24E-03	1.43E-03
Freshwater eutrophication	1.42E-03	1.96E-03	2.49E-03	2.76E-03	3.03E-03	3.57E-03	4.10E-03
Marine ecotoxicity	6.48E-02	9.03E-02	1.16E-01	1.29E-01	1.41E-01	1.67E-01	1.92E-01
Natural land transformation	1.41E-08	1.93E-08	2.45E-08	2.70E-08	2.96E-08	3.48E-08	4.00E-08
Terrestrial acidification	3.65E-02	5.06E-02	6.47E-02	7.17E-02	7.87E-02	9.28E-02	1.07E-01
Terrestrial ecotoxicity	9.36E-04	1.29E-03	1.65E-03	1.83E-03	2.01E-03	2.37E-03	2.72E-03
Urban land occupation	1.37E-02	1.91E-02	2.46E-02	2.73E-02	3.00E-02	3.55E-02	4.09E-02

**TABLE 6 |** Sensitivity analysis results for quantitative variations across each endpoint impact category for operations phase (in species.yr).

Impact categories	-50%	-30%	-10%	0	10%	30%	50%
Agricultural land occupation	1.83E-07	2.23E-07	2.64E-07	2.84E-07	3.04E-07	3.45E-07	3.85E-07
Climate change, ecosystem	3.34E-02	4.66E-02	5.97E-02	6.63E-02	7.28E-02	8.60E-02	9.91E-02
Freshwater ecotoxicity	9.92E-05	1.39E-04	1.78E-04	1.98E-04	2.18E-04	2.57E-04	2.97E-04
Freshwater eutrophication	1.21E-04	1.64E-04	2.08E-04	2.29E-04	2.51E-04	2.94E-04	3.38E-04
Marine ecotoxicity	1.57E-02	2.20E-02	2.82E-02	3.14E-02	3.45E-02	4.08E-02	4.70E-02
Natural land transformation	1.35E-10	1.88E-10	2.41E-10	2.67E-10	2.93E-10	3.46E-10	3.99E-10
Terrestrial acidification	2.85E-04	3.89E-04	4.92E-04	5.95E-04	5.95E-04	6.99E-04	8.02E-04
Terrestrial ecotoxicity	5.87E-03	8.22E-03	1.06E-02	1.17E-02	1.29E-02	1.53E-02	1.76E-02
Urban land occupation	3.63E-05	4.89E-05	6.14E-05	6.77E-05	7.40E-05	8.65E-05	9.91E-05

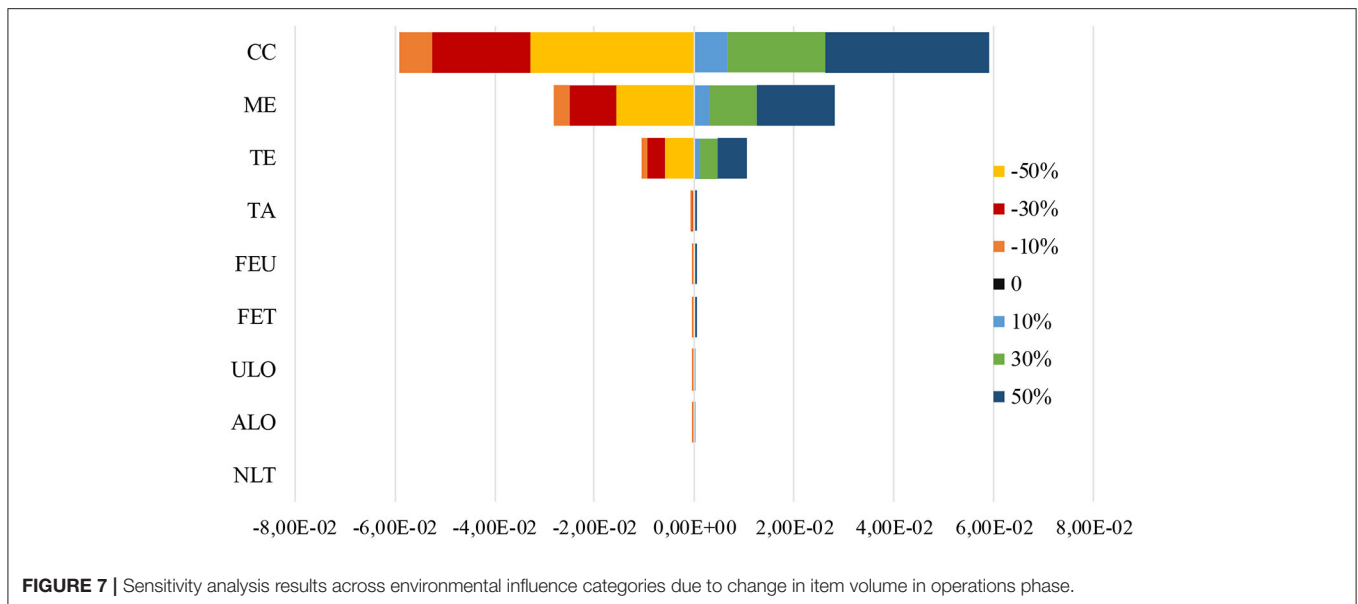


**FIGURE 6 |** Sensitivity analysis results across environmental influence categories due to changes in item volume in the construction phase.

the implementation of circular solid waste management in mega-sports events has to follow the waste management strategy of sorting, collecting, recycling, composting, energy recovering, treating, and disposing.

Participating and encouraging fans’ in-stadium schemes for recycling can be challenging. Fans’ engagement, attention, and awareness need operational efforts to reduce an environmental

footprint, reduce stadium’s waste, and an ecosystem damage reduction strategy through a participatory approach. Marketing campaigns and a video promoted on social media broadcasted on big screens during the event can be the most effective ways to introduce the home crew. This enables knowledge sharing through crowdsourced platforms to harmonize sustainability in the FIFA initiative. The seats from modular stadiums like



the RAA Stadium can be 100% recycled, of which 10% have already been recovered from the ocean for its current state design (SDG: 14). This will enhance the CE's value by using reused plastic from the hometown's waste to manufacture new seating platforms. Hence, adopting strategic waste management and recycling that, a CE initiative, would support the host nation in maintaining post-event legacy and meeting sustainability targets and goals.

Reusing wastewater and water conservation lead to significant environmental benefits, developing from decreases in wastewater discharge and diversion impacts on environmental water quality (SDG: 6, SDG: 7, SDG: 14). To bring out a balance to the anticipated ecological deterioration during the event, Qatar can implement policies to improve the efficiency of water, lessen the consumption per capita, and maximize recycling of treated industrial and sewage water for district cooling services, construction works, landscaping, and garden irrigation. Hence, adopting strategic wastewater management and circularity schemes can reduce the burden on the environment. Similarly, the CO<sub>2</sub> emissions in building materials (embodied CO<sub>2</sub>) developed by burning fossil fuels result in significant GHG emissions (~50%) (Primasetra, 2019). Therefore, the host nation needs to decrease the influences associated with embodied CO<sub>2</sub> emissions; one way is to use reused and eco-friendly materials for construction due to their low embodied energy. The materials used in modular stadiums can be reused once dismantled for several other building purposes with the State of Qatar. This creates a shared use of resources and a possible resource allocation. Reusing material is a part of designing a sustainable stadium that can significantly impact the environment. The material used in this process shall be scheduled at the beginning of the design phase, which can be found in the electrical fitting, flooring, finishes, etc. of the stadium (SDG: 11, SDG: 12). Planning is essential to maintain sustainability long after the event.

Approximately 60 tons of waste by game can be produced. However, through proper recycling and composting systems, more than 95% of this waste will be removed from landfills. The recyclable or compostable materials can be utilized based on extensive selection and agreement with stadium vendors, which is the best way to accomplish this task (Aquino and Nawari, 2015). For example, the cyclopean concrete (CYC) methodology can be utilized, incorporating excavated boulders from the site within the concrete mix for under-raft foundation casting for future stadium designs. In comparison with the traditional concrete casting approach, this approach reduces the environmental and economic burdens. The study concluded that GHG emissions were reduced by ~32% by adapting the CYC technique in Al-Jonoub Stadium in Qatar. Therefore, the CYC approach achieves the vital low-cost and unconventional material from waste crops existing in Qatar, enhancing the lesser environmental influence than the traditional concrete casting (Al-Hamrani et al., 2021). Thus, understanding and rethinking ecological quality through possibilities of the circular collaborative economy can considerably reduce the ecosystem damage to achieve sustainable development goals for mega-event hosts long after the event.

In addition, following CCE strategies can aid in harmonizing several other socioeconomic and environmental initiatives with SDGs to foster the event legacy and avoid possible ecosystem damage, namely:

1. SDG 1: Involving exclusive social groups of the population, waste pickers, or association of waste pickers for working in FIFA events (during and post-event).
2. SDG 6: Setting norms on water saving and water cleaning, reusing wastewater, and water conservation or facilitating boxes with free water in recyclable cups.
3. SDG 8: Seasonal and regular green jobs in circularity, it is any job or profession that directly includes or indirectly supports one of the strategies of the circular and CCE economy and



**FIGURE 8 |** Benefits of modular stadium design to leverage ecological burden, aligned to UN SDGs and LOC agenda.

climate change prevention. There are three types of circular green works: main, auxiliary, and indirectly related to the support in FIFA on every stage of LCA chains in waste and resource management, marketing, engineering, building, transport, etc.

4. SDG 10: Environmental and social justice for all groups of stakeholders, equal rights to affordable and quality resources and services, including in-process CCE system service.
5. SDG 16: Creating new social, environmental, and economic structures and institutions under sustainability and circularity.
6. SDG 17: Creating and strengthening of collaboration chains with NGOs, scientific sector, public–private partnership, and customers in CCE on all levels of the life cycle

stages, promoting event legacy—historical and cultural capital of mega-events with environmentally friendly value creation.

## CONCLUDING REMARKS AND FUTURE WORKS

The research quantified the ecosystem damage-related impacts to better understand the ecological quality in life cycle impact assessment for modular container stadiums taking the case of the RAA Stadium in the State of Qatar using a cradle-to-cradle LCA approach. The study presented EOL management through



**TABLE 7** | Influencing factors on ecological quality for Ras Abu Aboud Stadium case study.

Life cycle phase	Influencing impact category		Influencing material/activity	
	Item	Ecosystem damage (species.year)	Item	Value (species.year)
Production phase	CC	$6.05 \times 10^{-1}$	Concrete	$4.25 \times 10^7$
Construction phase	CC	$3.64 \times 10^{-8}$	Freight	$7.97 \times 10^{-1}$
Operation phase	ME	$1.96 \times 10^{-8}$	Waste generation	$5.45 \times 10^{-2}$
End-of-life phase	ME	$9.34 \times 10^{-1}$	Concrete	$4.25 \times 10^7$ (savings)

an impact quantification method along with a perspective analysis through the lens of the circular collaborative economy in aligning the FIFA World Cup 2022 initiatives with UN SDGs and reducing the ecological burden during, before, and post-event. A sensitivity analysis was carried out to investigate the extent of impact per category indicator subject to material quantity variations. E-LCA results highlighted the contributing life cycle phase and material/activity for each impact category. Four main life cycle phases were considered for the assessment: production, construction, operation, and EOL phase. For the operations phase, two scenarios were considered: 1 year of operation, after which the stadium would be dismantled, and 30 years of operation, to compare the impact of a long-term operation on the different impact categories. The results of the study are summarized in **Table 7**.

The results of the sensitivity analysis revealed climate change as the most sensitive impact category for possible parametric variations. Considering the post-event scenario, the authors suggest alternatives for the future application of shipping containers apart from the current target to use the containers overseas for sports complex facilities such as constructing container restaurants, schools, retail stores, coffee shops, students housing, commercial offices, art galleries, portable toilets, indoor garden area, sedan garages, cold storages, medical facilities, libraries and warehouses, swimming pool and mobile jacuzzies, transportable greenhouses, and container movie theaters, which have a visually pleasing aesthetics and are cost-effective. In addition, the containers can be reused to build compact shipping container homes and lodgings that can provide characterful eco-friendly living spaces for tourists that visit Qatar post-2022. Several peer-to-peer rental platforms such as Airbnb most seek such compact container mansions to preserve the badge of sustainability while delivering services. This can help Qatar maintain a post-2022 legacy and help Qatar generate a new market for sharing economy and eco-friendly tourism, a sustainable slant for development.

Alternatively, the authors suggest using sustainable and green element substitutes while constructing similar demountable infrastructures in the future. The authors recommend

considering the reuse of the material options from the beginning of the design phase. Using green steel on roofs reduces energy consumption, which eventually reduces GHG emissions because it helps to reduce the heat island effect, which can assist in lowering the indoor temperature by up to 5°F and resulting in a possible energy savings of up to 5%. Another example of upgrading the lighting fixtures of efficient LED lighting (when possible) offers instant paybacks in cost vs. benefits that are estimated at \$32,000/year per fixture. Installation of glass-reinforced plastic as a waste management system in lieu of concrete or steel material will reduce a huge amount of CO<sub>2</sub> and reduce the amount of GHG emissions. Moreover, window glass and frame material have significant impact levels on environmental performance, which must be considered during the design phase. Therefore, utilizing glass-reinforced plastic window frames as substitutes to the traditional glass window can improve the energy performance and potential energy at the product life cycle, thermal performance, and structural performance (Katar, 2017).

The presented research act as a roadmap for developing economies that target to address sustainability when hosting future World Cup mega-events; however, the research study was conducted during the construction phase of the RAA Stadium; therefore, there is plenty of assumptions made regarding the operational phase data provided by the World Cup 2022 hosting committee. However, this limitation can pave the way for further research in this selected area of knowledge by conducting a post-World Cup impact assessment study. The authors recommend using “life cycle sustainability assessment (LCSA),” extending the study to include social impacts such as human health and quality of life through a social-life cycle assessment, life cycle cost approach to understand the economic sustainability in constructing modular stadiums for carbon-neutral mega-events and resource depletion damage using an E-LCA approach. It is also suggested that when a close relation to the ecological objectives is necessary, the ecological scarcity approach is better used. The EPS approach can also give politicians and reform advocates useful guidance. Finally, it has been concluded that ReCiPe’s strongest asset is that it helps product analysis to consider diverse philosophies. The current study has focused on evaluating the ecological quality of using container stadiums for hosting mega-sporting events. The CCE strategies presented for the EOL phase can be extended in a more detailed study that would quantify the benefits and costs of each alternative, which would, in return, help in better decision-making. Also, applications of more advanced multi-criteria decision techniques would further assist decision-makers in choosing the best alternatives while incorporating green design practices and possible retrofits.

## DATA AVAILABILITY STATEMENT

The original contributions presented in the study are included in the article, further inquiries can be directed to the corresponding author/s.

## AUTHOR CONTRIBUTIONS

MK: conceptualization, method, formal analysis, and supervision. NO: method, analysis, and writing. AK: methods,

formal analysis, visualization, and writing. NA: writing, editing, and reviewing. NA-A: writing and visualization. AN: writing literature review and formal analysis. All authors contributed to the article and approved the submitted version.

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