Received: 30 May 2025 | Revised: 2 October 2025 | Accepted: 30 October 2025 | Published online: 10 December 2025

RESEARCH ARTICLE

Green and Low-Carbon Economy
2025, Vol. 00(00) 1–12
DOI: 10.47852/bonviewGLCE52026301

BON VIEW PUBLISHING

Sustainable Construction Logistics, Part 1: A Theoretical Research Approach

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Abstract: This study aims to explore the sustainable development of construction logistics based on a conceptual framework. This study investigates how the criteria of sustainability, benchmarking, and orientation management of construction projects can support the sustainable development of construction logistic practices. General indicators and criteria of sustainability are first developed to be in integrated with the construction logistic plan and used as a basis for benchmarking and orientation management of urban stakeholders of construction projects. This can help in tracking changes in environmental, social, and economic conditions affecting the logistic operations of construction projects and can make construction companies more adaptable to hidden factors and unexpected problems related to sustainability. Benchmarking can open construction companies to new sustainability methods, ideas, and tools to continuously improve their effectiveness. Orientation management of stakeholders will lead to increased awareness among stakeholders and project actors, thereby improving logistic operations throughout the supply chain to create an efficient organization focused on sustainable development. Other aspects related to the sustainability of construction logistics are also discussed in this paper.

Keywords: sustainability, orientation, benchmarking, construction logistic plan, stakeholders

1. Introduction

The disruption of natural, economic, and social systems due to the impact of climate change and environmental pollution is adversely affecting the daily life of every human being globally and locally. Sustainable development can be described using three dimensions (or core principles): environmental, social, and economic dimensions. Environmental sustainability aims to protect and preserve the environment by promoting the use of renewable energies and resources, mitigating the adverse effects of pollution on climate change biodiversity. Economic sustainability emphasizes economic growth with the help of a sustainable approach, which promotes green technologies and fosters innovation that contributes to the well-being of society. In general, social sustainability implies improving the life quality of people and aspects of social life. The global building sector accounts for 35% of the final global energy consumption, corresponding to 38% of global CO_2 emissions [1]. Consequently, the sustainable development of the building sector becomes an important issue to be considered because pollution will have its adverse effects not only on the environment but also on the economy and society. As construction sites place high demands on logistics, especially when buildings are established in dense urban areas, managing construction logistic operations in a sustainable way will contribute to the general sustainable development of the building sector.

Supply chain management is the management of the efficient forward and reverse flows of goods and services that are essential to the operations of an organization, including all processes of turning raw materials into final products [2]. Technically, logistics is the overall process of planning, implementing, and controlling the efficient transportation and storage of resources (services and goods) from the point of origin to the final destination. Construction logistics is part of supply chain management and refers to the management of the physical storage and movement of equipment, tools, materials, and personnel from the point of discharge to the location of the construction site [3].

Accordingly, the goal of sustainable construction logistics is to ensure that construction materials and equipment are delivered to the construction site in time and in the right quality and quantity at the lowest possible cost on economy, society, and environment. Conversely, inefficient logistic operations in a construction project can adversely affect labor productivity and can cause project delays, increase environmental pollution, cause adverse impacts on nearby residents, and cause cost overruns due to an uncompleted project within the budget [4]. Efficient logistic practices can lead to the following:

1) better planning for future cities and construction projects [5],
2) increasing labor productivity [6],
3) decreasing overall costs of logistic operations [7],
4) building a competitive advantage [8],
5) creating innovative solutions for warehousing processes [9],
6) contributing to organizing construction logistics and transportation in a sustainable way, particularly within urban areas [10],
7) solving problems related to material handling, storage, packing operations, and consequences of lack of control [11].

One may add here that the sustainable development of construction logistics can pave the way to the satisfaction of urban stakeholders, as discussed later on. In this context, efficient logistics of material processes is important for maintaining safety, productivity, and coordinated schedules and for facilitating the construction of building projects. Site work logistics depend on the resources, material storage and staging, fabrication, transport, and distribution before the delivery [4]. Consequently, the sustainable management of construction logistics should consider and identify all variables needed to keep work moving forward toward sustainability.

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A number of studies have been published on the subject of sustainability in construction logistics. Brusselaers et al. [12] presented a sustainability assessment framework designed for construction logistic activities based on life cycle approaches. Morel et al. [13] studied the governance strategies for realizing more sustainable urban construction logistics to determine which drivers for collaborative governance are needed to improve urban construction logistics. Balm and Ploos van Amstel [14] studied tendering for construction projects as a supporting tool for sustainable urban construction logistics by both public and private clients.

Colicchia et al. [15] empirically investigated the significant role of "logistics service providers" in reducing the environmental burden of the supply chain with respect to environmental sustainability for logistics and transportation. Lieb and Lieb [16] examined environmental sustainability initiatives undertaken by logistic companies and the impact of these initiatives on "third-party logistics" (TPL) and their customers. Whitlock et al. [17] investigated the benefits of using building information modeling (BIM) for construction logistic management as a tool for improving logistic operations. Adetunji et al. [18] investigated the meaning, barriers and enablers, issues, tools, and techniques for achieving successful sustainable construction and supply chain management. Liu and Ma [19] investigated the use of "the Internet of Things technology" as an important part of modern intelligent systems to reduce the environmental pollution of the logistics industry. Wichaisri and Sopadang [20] presented a framework for a sustainable logistic system to be used as the basis for analyzing the inputs and outputs of a case study (sugar factory). Björklund and Forslund [21] explored the implementation of sustainable logistic innovations to improve the sustainable development of logistic operations. Audretsch et al. [22] empirically investigated sustainable orientation management and institutional quality to enhance productive-growth-oriented entrepreneurial activities. Wagner [23] investigated the impacts of the freight-related activities of air pollution, noise, and traffic congestion on the living environment and land use. Morais and Silvestre [24] analyzed why and how focal companies implement and manage social sustainability in their supply chains. Mota et al. [25] proposed a multiobjective mathematical programming model for supply chain design and planning to integrate the three dimensions of sustainability. Nicoletti and Appolloni [26] investigated how artificial intelligence, particularly foundation models, can contribute to green logistics by optimizing routes, reducing packaging waste, and improving warehouse layouts and other related functions. In the same context, a literature review was conducted by Tetteh et al. [27] to examine the antecedents, practices, and performance outcomes of the green logistic practices. Yasir et al. [28] evaluated the effectiveness of passive design strategies (e.g., natural daylighting and night flushing) combined with the integration of photovoltaic (PV) systems and battery storage in reducing carbon emissions in a logistic center located in Sweden. Vrijhoef and Harmelink [29] investigated how the concept of the construction logistics control tower (CLCT) in urban construction logistics can help in exchanging data and information to improve decision-making and reduce the negative effects of construction transport.

In this paper, the sustainability of construction logistics will be studied in view of another perspective. It aims to derive sustainability indicators and criteria for construction logistics to enhance the sustainable development of the construction logistic sector. This paper presents general indicators and criteria for sustainability and discusses how these can be integrated with the logistic practices of construction projects such as the construction logistic plan (CLP), construction consolidation centers (CCCs), and TPL and can be used as a basis for benchmarking and orientation management of urban stakeholders of construction projects. The indicators and criteria of sustainable construction logistics are important for the planning and control of the logistic operations of the construction site, as discussed in Section 2. As such, the indicators and criteria can play an active role in improving the formulation of the strategies for logistic operations and planning of policymaking processes. Further, the role of benchmarking and orientation management to support the sustainability of logistic operations is discussed in Section 3. Benchmarking helps in identifying the present state in comparison to the past state and in predicting the future trends of logistic operations of construction companies. Orientation management of stakeholders implies identifying stakeholders' needs and using them as a basis to enhance the sustainable development of logistic practices because the quality of a company's relationships, awareness, and engagement with its stakeholders can be decisive factors, as discussed in Section 4.

This study presents a conceptual framework that integrates well-established elements—such as environmental, social, and economic sustainability criteria—with construction logistic practices, benchmarking, and stakeholder orientation. It is noteworthy to indicate that these individual components are already documented in the cited literature. However, this study attempts to integrate these components together to optimize sustainability solutions and support the identification of applicable best practices that could be implemented in their own professional contexts.

1.1. Methodology

This paper adopts a conceptual approach and is built on a foundation of established theories and ideas from sustainability, construction logistics, and stakeholder management. The framework is developed mainly with the help of literature synthesis and inputs from a number of construction logistic projects in Sweden and England.

The scope of this study is limited to deriving only the general criteria of sustainable construction logistics that are thought to be practically important to consider when designing sustainability solutions.

This study is divided into two parts. In the first part, the research methodology used is qualitative conceptual framework. The second part of this study, which will be presented in a subsequent paper, will treat the quantitative sustainability assessment of construction logistics based on the findings of this paper. This includes the development of practical examples and empirical results that illustrate how the proposed approaches can be implemented on-site.

2. Indicators and Criteria of Sustainable Construction Logistics

The sustainability of construction logistics is based on three general indicators: environmental, social, and economic indicators that address the impacts that arise from construction logistic operations and the measures to tackle the consequences of the impacts. Each indicator will be composed of a number of criteria. The criteria imply a challenging problem that needs to be carefully considered to achieve a certain level of sustainability in the construction logistic practices. Technically, a criterion is a measurement of one aspect of the indicator. It is a quantitative or qualitative variable that can be measured or described and should clearly demonstrate trends when observed periodically [30]. Project managers can control the level of sustainable development of a construction project by following the course of a criterion over time and make value judgments regarding whether the course is positive, negative, or neutral.

The criteria of sustainable logistics may be categorized as general and special. General criteria are those that are common in every construction project, whereas special criteria are specifically related to a construction project. These can significantly vary from one construction site to another depending on the circumstances challenging the project because construction logistics can have many different variables and some adverse factors such as the space presented for site works, which can be an effective factor for all logistic processes [3, 4].

2.1. General criteria of sustainable construction logistics

The following indicators and criteria for the sustainable management of construction logistics are presented.

2.1.1. Environmental indicator

This indicator is composed of a number of criteria as follows:

1) Minimization of air pollution

Oil combustion in the transport sector is a major source of carbon dioxide and oxides of nitrogen emissions worldwide, contributing to global warming [31]. The main greenhouse gases produced by vehicles during oil combustion are carbon dioxide, nitrous oxide, and methane, which can cause smog, poor air quality, and development of acid rain in certain cases. Another pollutant released from vehicular traffic is the airborne particulate matter [32]. All of these problems can adversely affect human health and can deteriorate air quality. Subsequently, goods that are transported inefficiently at long distances will increase air pollution. To reduce the environmental impact of air pollution due to transportation, the following measures can be helpful in this respect:

a. Transporting construction materials and equipment to sites during off-peak periods will reduce CO_2 emission.
b. Using electric vehicles can lead to reduction in air pollution [33].
c. Decreasing the number of transportations from and to the construction site using CCCs can minimize air pollution [34].
d. Using alternative fuels such as hydrogen fuel (liquefied natural gas) in vehicles instead of diesel can result in a clean burning process that produces lower tailpipe CO_2 or NOx [35].
e. Following the environmental guidelines and legislations with respect to logistic operations will minimize the adverse effect of air pollution.

2) Minimization of soil pollution

Soil pollution due to vehicular traffic can be a major concern in some cases because it can result in soil erosion and soil contamination. The removal of the Earth's surface for highway construction or lessening surface grades for airport developments can lead to important loss of fertile and productive soils [36]. In addition, soil contamination from vehicle emissions releases particulates, trace elements, and hazardous heavy metals such as arsenic, cadmium, chromium, copper, lead, nickel and zinc, PAHs, and road salts into the environment [31]. These contaminants arise from a variety of sources and processes, including the following:

a. incomplete fuel combustion,
b. oil leaking from engine and hydraulic systems,
c. fuel additives,
d. road and tire abrasion,
e. brake dusts,
f. road surface leaching,
g. traffic control device corrosion,
h. direct application of road salts (to prevent the sliding of vehicles on snow) [31].

Hazardous materials and heavy metals have been found in areas contiguous to railroads, ports, and airports [36]. The measures to be taken to minimize soil pollution due to vehicular traffic are the following:

a. To perform regular control on vehicles to ensure complete fuel combustion and that there is no oil leaking from engine and hydraulic systems and no road surface leaching occurs. In addition, fuel additives must only be accepted in accordance with environmental guidelines.
b. To decrease the number of transportations from and to the construction site through careful logistic planning, which take into account transportation time, number of transportations, and vicinity of construction sites to residential areas.

3) Minimization of nonrenewable energy sources

From a sustainability point of view, fuels should be derived from renewable resources. In many cases in practice, vehicles and trucks used in logistic operations use fuels that are derived from nonrenewable sources (fossil fuels such as petroleum). This situation represents additional challenges for construction projects from a construction logistic perspective. Alternative fuels that can be derived from renewable energy sources include methanol, propane, ethanol, electricity, hybrid electricity, biodiesel, and hydrogen fuel cells. Using trucks that run on electric and hybrid fuel instead of diesel fuel will result in less negative impacts on the environment [37]. For any operator whose daily operations are within 300 km, an electric truck is a practical fossil-fuel-free option [35] if the electricity is derived from a renewable source. Although hydrogen fuel is a zero-emission fuel, it is often produced from fossil sources, namely, natural gas and coal. Construction companies will be able to explore creative solutions to the problem by prioritizing vehicle technology based on renewable energy sources. This concerns the logistic operations and the construction site to reduce emissions, support green energy, and design green buildings.

Nonrenewable fuel is often used in machines and equipment in construction sites. Renewable energy sources such as solar, hydro, bio, and wind energy are sustainable alternatives that can reduce the dependence on nonrenewable energy sources.

4) Maximization of quality of urban systems

Construction projects can affect the ecosystem around the construction sites, especially for construction projects near forest and water areas. The destruction of forests and water areas contributes to the decline in biodiversity and accelerates climate change. In addition, logistic operations to and from construction sites can adversely affect the internal environment of adjacent properties, business areas, schools, and nearby residents. Even the working environment at the site can be negatively affected by unorganized loading and unloading routes of freight movement. In general, the disruptive impacts on urban systems and urban life can affect the socio-spatial relations in contemporary cities [38].

The development of a sustainable logistic strategy for freight movements related to construction sites, which takes into account the negative impacts on the external and internal environments of the urbanization areas, will minimize the disruption of urbanism and improve the quality of urban life. The quality of urban systems can also be related to the noise levels emitted by the freight movements to and from construction sites, as discussed below.

5) Minimization of noise and vibration levels

In construction sites, the control of airborne noise and structure-borne sound and vibration due to logistic operations to and from construction sites need to be addressed. Traffic noise is the most common source of noise pollution in urban areas. It includes sounds from cars, trucks, and railway tunnels. Noise can also be generated during the removal of demolition materials from sites and construction of new structural works. In many cases in practice, the generated noise and vibration levels from construction sites, including traffic, are high and can be annoying to nearby residents and workers at the construction sites. Reduction of high noise levels due to logistic operations will improve the life quality of the nearby residents and labor productivity of construction workers because long-term exposure to noise may cause serious health effects [39]. To reduce the high noise levels at the construction sites due to freight movement to and from the sites, a careful schedule planning for transportation should be performed and noisy vehicles and equipment (noise sources) should be placed away from workers and nearby residents. In some cases, noise barriers in construction sites may also help in shielding nearby residents and workers from sources of noise pollution related to construction activities [40]. At any rate, a noise control plan may be developed to identify, monitor, and minimize the impact of noise in construction sites. Further, construction workers are often exposed to excessive noise on construction sites. Consequently, there should be a need to perform continuous health and safety risk assessments of workers. Acoustic consultants may also contribute their expertise in this context.

6) Minimization of dust emission

Dust emission can occur during the removal of demolition materials from construction sites and from the removal of generated site waste during construction. Occasionally, the freight movement to and from the construction site can cause dust emission, especially with high wind velocity and dusty roads. Dust emission adversely affects on-site workers and residents in areas adjacent to construction sites. Regular breathing of construction dust can cause diseases such as lung cancer, asthma, chronic obstructive pulmonary disease (COPD), and silicosis [41]. Some dust types can also bear health risk to some people who are suffering from allergy. To minimize dust emissions, it is important to develop a control plan for dust emissions during on-site construction activities, including the possible use of dust suppression systems. Dust–wind screens and containerization can also be a practical solution for problems related to bulk material transportation [42].

7) Minimization of congestion

Traffic congestion related to construction activities can adversely affect sustainable development, particularly in densely populated areas. High congestion on and off construction sites can be a result of poorly planned freight transport (e.g., inefficient planned deliveries and scheduling). By careful planning for urban freight movement and space usage, especially in populated cities with limited space on roads, vehicle trips to and from construction sites can be reduced in peak periods. For example, congestion can be minimized by delivering an effective timetable of journey planning that facilitates the reduction of vehicle movements to and from construction sites to be within peak travel times. In this context, it is observed that cities with extensive transit systems experience lower congestion levels [43]. Moreover, by developing an efficient material handling system, heavy vehicles can be quickly unloaded to diminish the resulting congestion and waiting time on sites. The use of CCCs can also contribute to the reduction of the number of deliveries [44]. Solving the problem of congestion will have its positive consequences on the urban economy and will reduce air pollution in addition to annoying noise and vibration levels.

8) Minimization of waste generation

In practice, construction companies place high demands on the removal of waste and debris from construction sites. Construction waste is generated mainly as a result of used and unused construction materials and demolition waste. Some construction materials will be damaged due to weather conditions and lack of control due to poor planning of construction materials and storage. In addition, in some cases, construction materials are ordered in large quantities without actual need in constructions, which will result in waste generation. The lack of supervision may also lead to the loss of construction materials. Consequently, these technical problems will increase the size of waste transportation to landfills in addition to the increased costs due to unused, damaged, or lost construction materials. The situation can even be worsened if hazardous residues of some construction materials are to be handled as wastes, e.g., asbestos, PCBs, brominated or chlorinated flame retardants, mercury, lead paints, plasticizers, and metal- and POP-containing wood preservatives [31]. This type of hazardous waste can pose a potential risk to the environment and human health. Minimizing the creation of waste in both the design and build phases of construction and using environment-friendly building materials will consequently improve the economic and social dimensions of sustainability.

9) Maximization of recycling and reuse of waste material

The generated construction waste that cannot be recycled or reused will often be transported to landfills. The recycling and reuse of construction waste can prevent the loss of valuable resources to landfills. Waste minimization and waste recycling/reuse will therefore have a positive impact on the costs of waste transportation operations and the overall cost of construction projects [30].

2.1.2. Social indicator

This indicator is composed of the following criteria:

1) Minimization of road risk

Construction sites are often located close to main road traffic junctions, which implies frequent freight movements to deliver materials and equipment to and from the sites. Subsequently, a number of issues will have to be addressed to improve the safety of workers, road users, and nearby residents to avoid car accidents and other road risks related to loading and unloading of freights. The safety of road users requires a development of a traffic plan that satisfies the road users and pedestrians. It is observed that the increased number of heavy vehicles, together with speed changes and increased travel distance, can result in a safety issue as it increases the risk of road accidents [45, 46]. Moreover, material storage, loading and unloading of vehicles, and traffic congestion pose risks of personal injuries. Technically, road risk injuries can adversely affect the physical and psychological safety of the local community and its welfare system.

2) Maximization of safety and health of construction workers

The construction industry is one of the industries with most fatal accidents. Every year, more working days are lost due to work-related illness compared to injuries [47]. Construction workers are exposed to different risks for health and safety as they engage in many activities that may expose them to injuries, work-related illness, and fatal accidents [48]. This also includes workers involved in the logistic operations at the site because the supply of construction materials and equipment on and off the site poses a safety and health risk for construction workers. Moreover, it is observed that construction employees can, in some cases, experience occupational psychological disorders due to their work, personality characteristics, or lifestyle [49]. Subsequently, the supply of construction materials and equipment with high occupational safety and health margin needs to be considered in sustainable logistic planning.

3) Maximization of comfort of living

Comfort of living is closely related to the environmental indicator. For instance, noise, vibration, smog, and dust from freight movement and machines to and off construction sites can cause dissatisfaction to nearby residents. Communities living near construction sites can have bad air quality due to dust and air pollutants, which can eventually result in respiratory diseases. Even health and safety risks can be a result of long exposure to noise and dust, which affects the well-being and welfare of the community because repeated exposure to loud noise can lead to stress and, in some cases, to hearing loss and health risks. Due to the presence of construction sites and related logistic operations in populated cities, the economic value of the land and neighboring properties will also be negatively affected. Access to nearby shopping markets and business units can be disrupted or limited due to the presence of construction sites, which can be disturbing to residents, customers, and eventual residents' relocation. Further, disruption of comfort of living in an urban development can negatively affect the external stakeholders associated with the construction project, along with their surrounding environments [50]. Consequently, the impact of construction logistic operations on the social and economic indicators of sustainability needs to be carefully addressed on the short and long term to advance innovative measures to tackle this problem. For instance, freight transportation can result in economic growth, but it can be a major concern for sustainability components [51].

4) Maximization of cultural values of cities

The aesthetic aspects and heritage status of cities (cultural and social values and spiritual sites) can be affected negatively due to the presence of construction sites and its supply chain. For instance, cultural heritage sites can be damaged or destroyed accidentally. They can even be deliberately damaged during logistic operations and construction works. In some cases, construction plans led to severe opposition, protests by citizens, court hearings, and finally, a referendum [52]. In addition, due to the logistic operations on the construction sites, road closures, signs, fences, segregation areas, and concrete blocks are established. It can sometimes take longer times to dismantle them when the construction project is complete. This situation can adversely affect the aesthetics of the city and comfort of living, thereby causing dissatisfaction among nearby residents and urban stakeholders [48]. Construction waste can even result in aesthetically unattractive surroundings and loss of land [53].

Solutions for the problems related to the social indicator of sustainability may be carefully planned by identifying and assessing the adverse impacts of each criterion, which can vary depending on the social circumstances of the communities. One important measure in this context is to promote public policies that support social sustainability.

2.1.3. Economic indicator

In general, the economic dimension of sustainability involves promoting resource efficiency and minimizing waste throughout the supply chain. This can be achieved by improving resource management practices and reducing the environmental impact of economic activities without negatively affecting the social, environmental, and cultural aspects of the community. In this context, the economic indicator can be composed of the following criteria:

1) Maximization of innovation toward sustainability

Maximization of innovation toward sustainability implies exploring new innovative methods that help construction companies work toward sustainability. One of the steps to be taken in this respect is making an investment plan for achieving sustainable logistic practices. An investment involves using capital in the present to increase sustainability value over time.

Technically, construction logistic costs include three key components: transportation costs, inventory or warehousing costs, and administration costs [4]. Additional costs may thus be added to the budget to investigate sustainable logistic methods that can benefit the society, environment, and economy. By creating innovative sustainable solutions, a competitive advantage can gradually be built to enable construction companies to produce sustainable methods better than competitors do. Sustainable logistic methods are based on satisfaction of the criteria of sustainable development. For example, by exploring fossil-free fuel in vehicles and fuels with minimal impact on the environment along with methods to reduce freight movement to and off the constructions site, logistic operations will gradually be sustainable. It is important to obtain knowledge from successful companies through strong business cases to accelerate the sustainable development of logistics [21]. It can be added here that benchmarking of companies with respect to sustainability can also contribute to the accumulation of knowledge necessary to innovate methods and approaches toward sustainability, as discussed in Section 3.

2) Minimization of disruption cost

As mentioned earlier, construction sites and logistic operations can result in the disruption of nearby businesses due to the resulting dust, noise, segregation areas, and subsequent deterioration of business operations. This situation can adversely affect the economy of the community. It can be added that delays in the delivery of materials due to congestion and increased travel distance can even decrease labor productivity. The problem can be minimized by identifying and sorting the major root causes of the socioeconomic disruptions caused by dense urban construction [46]. Consequently, minimizing the disruption costs will result in increased labor productivity and the economic sustainability of the community.

3) Minimization of the cost of construction waste

As mentioned earlier, construction waste can often be a result of defective materials, poorly used materials, poor fabrication, and demolition waste. Freight movements to transport waste to landfills and the incurred costs are directly proportional to the size of the waste. To minimize construction waste and obtain cost savings, a careful investigation will be necessary to find out the source of waste and the possible solutions to minimize the size and impact of the waste. Reusing and recycling of waste at the construction site and using environmentally friendly construction materials such as timber can be some sustainable options to reduce the cost of construction waste.

4) Minimization of the cost of congestion

Cost due to the increased levels of congestion in the construction area is directly proportional to the costs for businesses and citizens [54]. Minimizing congestion by sophisticated planning of freight movement and highway engineering can reduce the negative impact on the economy, environment, and society.

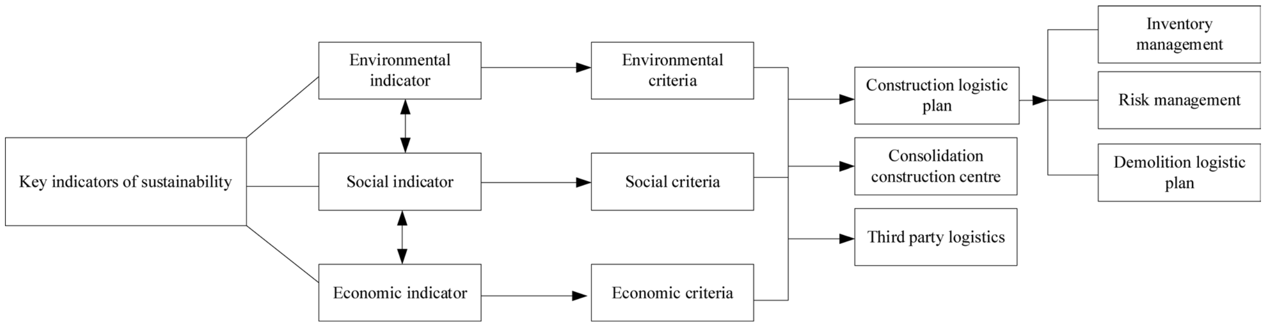
2.2. Interrelations between indicators

Figure 1 shows a model for interrelations between key indicators of sustainability with the basic aspects of construction logistics. The three indicators of sustainability are closely related to each other and interact with each other so that the successful implementation of one indicator should imply the successful implementation of the other indicators. On the basis of the abovementioned reviewed criteria, not only the environmental indicator of sustainability but also the social and economic indicators of sustainability can play a major role in improving the environment because they are related. For instance, construction waste generation will have its adverse impact on the environment, society, and economy.

The social indicator of sustainable construction logistics is related to satisfaction in the quality of life, health, and living comfort. In general, the social indicator of sustainability can affect both internal stakeholders (e.g., employees and the supply chain) and external stakeholders (e.g., community and society).

The environmental indicator of sustainable construction logistics is related to the environmental impact of logistic operations to and from

Figure 1
Model for the integration of the sustainability indicators and criteria with the basic aspects of construction logistic practices and operations



the construction site. Technically, environmental sustainability is crucial in minimizing the adverse impacts of climate change. Consequently, the global climate can be improved by reducing carbon emissions, promoting renewable energy, and ensuring equitable resource access, and resources will be not depleted. In general, the environmental dimension of sustainability mainly affects the external stakeholders. However, the internal stakeholders can also be affected due to the health effect of pollution on the employees.

The economic indicator of sustainable construction logistics is related to the sustainable practices that support long-term financial economic growth without destructively affecting the social, environmental, and cultural aspects of the community in the short and long terms. In general, the economic indicator of sustainability affects mainly the internal stakeholders. However, the external stakeholders can also be affected due to the economic consequences of logistic operations on the society, e.g., with respect to the welfare system, employment rate, and community services.

2.3. Integration of sustainability criteria with operations of construction logistics

To achieve the desired sustainability level in the operations of construction logistics, the criteria reviewed in Section 2.1 may be integrated with the CLP, the management of CCCs, and the management of TPL.

2.3.1. Sustainable construction logistic plan

All construction projects must technically have a CLP, including a waste plan, and delivery plans for building materials. CLP will usually be a part of planning application and gives the planning authority an overview of the expected logistic activity during the construction program. The CLP focuses specifically on construction supply chains and the reduction of their impact on the road network. Technically, the construction supply chain covers all logistical services, vehicles, and the workforce involved in a construction project and support procurement and transportation of materials, workers, and other resources to and from the construction site [4].

A construction project will have environmental, societal, and economic impacts on the road network, employees, and surrounding community. These impacts are directly proportional to the size, timescale, and location of the construction project and its related logistic operations. To create a sustainable CLP (SCLP), the sustainability indicators and criteria reviewed in Section 2.1 may be included in the contents of the CLP so that measures should be clearly stated to satisfy the criteria of each sustainability indicator (Figure 1). The integration of the sustainability criteria into the CLP to obtain an SCLP can help in turning a complex project into a well-harmonized event with lower costs, lower pollution, safer traffic lines, and efficient construction project operations. The consideration of the sustainability criteria in the CLP may be propagated to each component included in the CLP. In many cases in practice, a CLP will include an organized demolition logistic plan to deal with demolition works involved before rebuilding and for completely new buildings or structures.

A CLP can also include details on construction inventory management because an effective inventory management can reduce storage costs, environmental impacts, and their consequences on the community (Figure 1). Technically, construction inventory management deals with how to manage the construction assets: tools, equipment, and supply of materials required to build the project, including workforce, factories, and consumables provided to workers [55]. Consequently, warehousing and logistic operations should have an effective cooperation to ensure that products (materials, equipment, and services) are available at the right time and right place. Effective inventory management significantly influences construction logistics, primarily through waste reduction and the implementation of measures aimed at minimizing supply chain costs, thereby supporting cost-efficient logistic operations. However, to achieve sustainable inventory management, the indicators and criteria of sustainability may also be integrated in the operations of construction warehousing.

The other aspect of SCLP is risk management (Figure 1). In sustainable risk management, risk factors, including impacts on economy, society, and environment as a result of construction logistic operations, may be assessed carefully to develop a contingency plan to address these impacts.

2.3.2. Sustainable construction consolidation centers

A construction consolidation center (CCC) is a distribution facility for deliveries of construction materials and equipment, especially in congested urban areas. In a CCC, multiple shipments are consolidated and delivered by suppliers. These shipments are then combined into a single shipment to be transported by a single truck to the construction site or a number of different sites [3]. If the operations of a CCC are managed in a sustainable way throughout the urban development area, e.g., by considering the criteria reviewed in Section 2.1, the CCC can help in reducing construction transports, costs, and the negative impact on the environment and society (Figure 1). For instance, by recycling waste and using fossil-free fuel in the transports and services carried out by the CCC, the negative impact on the environment will be minimized. There is evidence that the use of the CCC can reduce air pollution due to urban freight transport [34].

2.3.3. Sustainable third-party logistics

The other aspect that should be coordinated with a sustainable CLP is TPL (Figure 1). From an instructive point of view, TPL describes when a construction company outsources its logistic fulfilment to external specialized service providers (TPL companies).

These companies target particular functions within the supply chain management, such as transportation, warehouse storage, inventory management, and material provision. Technically, the sustainability indicators and criteria may be integrated with the operations of TPL to achieve the level of sustainability envisioned by the construction companies. In addition, with the help of TPL providers, the design of inventories with respect to location, space, labor, and transportation will be carried out so that the negative impacts on the environment, society, and economy will be minimized and the positive impacts will be maximized. It is observed that efficient logistic service providers can contribute to the environmental sustainability of the supply chain [15] and minimize the warehousing and distribution costs for both forward and reverse product flows [56].

3. Benchmarking

3.1. Feasibility of benchmarking

A benchmark is a reference data point that can be used for future comparisons to find the best practices in a particular field [57]. Benchmarking can thus be a powerful management tool to achieve sustainability because it can allow for continuous improvement of construction logistic practices toward sustainability. As construction logistics covers construction management from creation to distribution and involves moving construction material and equipment through a supply chain, benchmarking as a methodology can offer the opportunity to identify the present state, in comparison to past state, and to predict future trends for the environmental, social, and economic aspects of sustainability. Benchmarking can also help in accelerating the sustainable development of logistics because it can contribute to the practical knowledge to be used by construction companies to continue with its logistic operations toward sustainability in a clear innovation process. In addition, the comparison of "best-in-class" can provide a powerful justification for own investment in continuous improvement to optimize logistic practices toward sustainability. Two types of benchmarking may be developed in this context.

1) Internal benchmarking

Internal benchmarking can be part of a CLP to track the development toward sustainability benchmarks within the same construction company. In this process, the project's progress is monitored and compared with predetermined targets to ensure that the construction project remains on schedule and on budget [58]. A pre-established target in this case can be local measures used to reduce the impact addressed by the criteria for sustainability, e.g., as reviewed in Section 2.1. Technically, project stakeholders may identify potential problems at an earlier stage to allow for an immediate corrective action as part of the continuous improvement process. This helps in avoiding potential problems due to inefficient minimization of adverse impacts such as uncontrolled waste, pollution, cost overruns, and costly delays.

2) External benchmarking

Construction companies may analyze the sustainability performance of their logistic practices and compare them with other construction companies to find out the best practices to achieve sustainability goals as addressed by the sustainability indicators and criteria. This can allow for advancing innovative methods to achieve sustainability of logistic practices and operations.

3.2. Benchmarking for sustainability performance

Each indicator and criterion of sustainability reviewed in Section 2.1 can be benchmarked when it is formulated into a measurable quantity under study. When comparing logistic operations for different construction projects, it is practical to look at the historical trend and study the resulting gap between results. Figure 2 shows an example of benchmarking of two companies with respect to the criterion "cost of construction waste" in which the objective is to minimize the cost. As can be seen, by projecting the future performance levels of a specific project's criteria of sustainability and benchmarking the best performance, the current rate of the improvement area required to match the performance of the best-in-class company can be found. Project managers may need to implement operational improvement actions, e.g., re-engineering of the operational process operations by applying the latest technological advances to close the benchmark gap [59].

The charts of benchmarking shown in Figure 2 are based on the quantification of a criterion. However, qualitative observations [57] can provide an operative tool to develop an improved process of sustainability.

The benchmarking analysis may be propagated to all sustainability aspects of construction logistics, including CLP, construction logistic centers, and TPL, as shown in Figure 1.

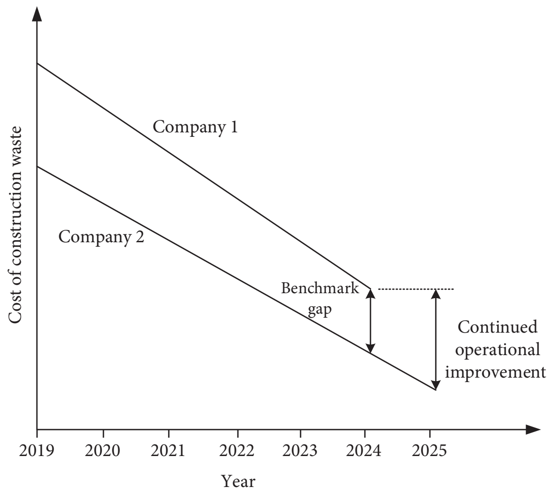
Using a benchmarking technique, logistic planning and the aggregation of experiences and expertise can be optimized, and comparison is subsequently used as an input for continuous improvement. Cooperation of benchmarking targets should be gained by sharing data with other construction companies [58].

A competitive benchmarking process will enhance not only the sustainable development of the logistic practices and operations of the construction project but also the satisfaction of urban stakeholders. However, it is noteworthy to indicate that there can be practical difficulties associated with collecting benchmarking data [60]. Another problem in this context is the resistance of stakeholders to change [61]. It is thought, however, that with the help of a carefully planned strategy for sustainability orientation, it is possible to minimize these problems, as discussed in Section 4.

4. Sustainable Orientation Management

Sustainability orientation is defined here as a management approach that focuses on identifying and meeting stakeholders' needs and preferences regarding sustainability. This involves designing and planning efficient construction logistic practices that satisfy these requirements. As construction logistic practices have to adapt to the principle of sustainable development, construction companies that work toward sustainability orientation consider the opinions and needs

Figure 2
Example of benchmarking of two companies with respect to the criterion "cost of construction waste"



of the stakeholders, including project actors, as a crucial component of continuous innovation and development. To be successful, companies need to ensure that all project actors and stakeholders adopt and promote the sustainability approach in all logistic practices so that it should become an integral part of corporate culture.

To maintain stakeholders' satisfaction and promote efficient sustainability practices, sustainability orientation aims at advancing innovative methods that satisfy the criteria of sustainability. Construction companies that have committed to sustainability goals can take existing logistic practices and focus their efforts on making them better or create new practices that can solve existing problems with respect to sustainability. Focusing on stakeholder's feedback and satisfaction can play a crucial role for project success in the construction industry, which can lead to creative solutions [62]. In this context, the criterion "maximization of innovation toward sustainability" (Section 2.1.3) can effectively be implemented with the help of the involvement and support of multiple stakeholders who have an interest or influence in the project.

With the help of a carefully planned strategy for sustainability orientation, it is possible to achieve a coordination of several construction project activities such as logistic operation planning, warehousing (storing building materials and equipment for the purpose of distribution), material handling, and workplace disposition planning.

A communication plan based on the indicators and criteria of sustainable development (e.g., as reviewed in Section 2.1) should define the target group or all players that play direct or indirect roles in the construction project, as discussed in the following.

4.1. Sustainable orientation of project actors

To help in promoting the principle of sustainable development within the framework of construction logistics, construction project actors should be well informed regarding the importance of applying sustainability in processes involving logistic practices. This can raise awareness regarding sustainable development and its positive impacts. Figure 3 shows an overview of typical construction project actors in a construction project. As can be seen, project actors form, in practice, networks of shared relations and interests that affect each other. Often, there are two types of links, which can be found between project actors: coordination and contractual bond [63]. The client or building owner holds the overall responsibility for construction management and is responsible for employment, procurement, supply, and financing of the project. The client is also responsible for approving the terms of the CLP and ensuring that the contractors comply with the agreed measures. Local planning authorities (or building authority) are responsible for reviewing and approving the outline and details of the CLP. Typically, they respond to complaints from the public and follow up on them with the client. The main contractor typically writes the detailed CLP and is responsible for regular management of construction sites and for ensuring that the terms in the CLP are implemented and followed. The main contractor, who has contractual bond with the client, is coordinating with different subcontractors and supplies to achieve project goals. Subcontractors and/or suppliers are responsible for carrying out specific activities to construct the building and to achieve the specific goals of the client, e.g., ventilation, plumbing, load-bearing structures, and insulation of the building envelope with respect to noise, heat, and moisture. The main contractor may also have a contractual bond with consultants (e.g., planning specialists and architects), civil contractors, and TPL to write the outline of the CLP for planning approval and prevent delays or conflicts.

The general indicators and criteria reviewed in Section 2.1 may be used here as a tool for orientation. The orientation of the project actors regarding the sustainability criteria and their role to enhance sustainable development can help in expediting communications between various actors, developing strategies, and taking measures for improvements that can be tracked and analyzed continuously. In the meantime, digital tools may be exploited to support working toward sustainable development. In this respect, the BIM can be used among site-based staff as a tool for enhancing knowledge of logistic information and developing sustainable solutions [17].

4.2. Sustainable orientation of stakeholders

The role of construction industry stakeholders is an essential part of all construction projects. Stakeholders are all groups or individuals that, directly or indirectly, have a vested interest or influence in all processes of a construction project [63]. Stakeholders of construction

Figure 3
Overview of construction project actors related to sustainability orientation

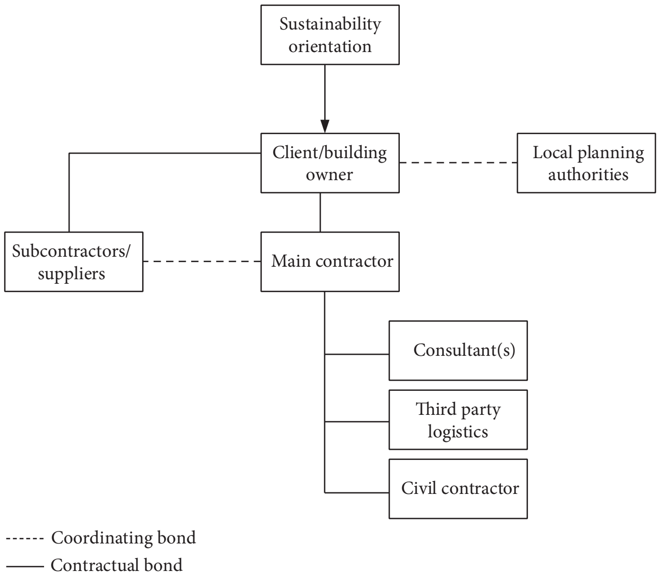
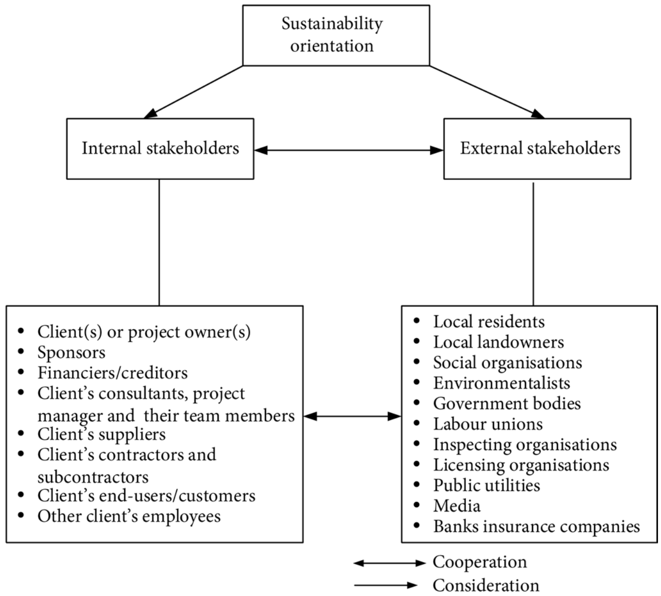


Figure 4
Overview of construction project stakeholders related to sustainability orientation



projects may be divided into two groups: internal and external stakeholders. Internal stakeholders are those who are directly involved in or associated with a contract with the construction project. External stakeholders are those who are indirectly involved or associated with the construction project. Figure 4 presents a typical stakeholder map of construction projects related to the management of sustainability orientation. To develop an effective strategy for sustainability orientation management of stakeholders, the collaboration between internal and external stakeholders should be improved to solve concerns raised by all stakeholders.

A sustainability-oriented approach to construction logistics can help internal stakeholders earn the trust and loyalty of external stakeholders. This approach can enhance the goals of sustainable development that the present needs are met without compromising the ability of future generations to meet their needs. In many cases in practice, both external and internal stakeholders can have dissimilar interests. An effective cooperation and engagement of all stakeholders may help in solving potential conflicts and advancing new approaches and methodologies to minimize the adverse impacts of construction logistic practices on the environment, society, and economics. It is worthwhile to indicate that ignoring a stakeholder can result, in some cases, in enormous effects on the construction project both in the long and short terms.

The indicators and criteria reviewed in Section 2.1 can be a starting point for stakeholders to develop innovative sustainable methods that enhance sustainable construction logistic practices. For instance, the adoption of renewable energy solutions to reduce carbon footprint and the minimization of waste generation by applying the principle of reusing and recycling of building materials will reduce the negative impact on the environment.

4.3. Engagement plan

A construction company can build its reputation by consistently meeting stakeholders' expectations and demands by maintaining sustainable construction logistic practices.

An effective sustainability orientation may address every aspect of supply chain management to create more efficient processes that support the criteria of sustainable development. After mapping the project actors and stakeholders, the client and consultant team can compile engagement plans that list how sustainable development criteria are satisfied and measures to minimize associated adverse effects. Technically, these plans can identify improvement areas, including threats and risks, for the sustainable development of the construction project.

An effective engagement plan enhanced by proper communication and collaboration among project actors and stakeholders can pave the way toward the satisfaction of external stakeholders and development of a corporate culture of continuous learning and feedback.

In general, by empowering and educating project actors and stakeholders regarding sustainable logistic practices, green technologies, and sustainable entrepreneurship that prioritize social innovation, environmental sustainability, and economic growth, a generation of visionary individuals who prioritize the sustainable development of construction projects can be nurtured.

Making an effective engagement plan requires a data-driven approach with transparency throughout the process. In practice, treating all stakeholders equally is a challenge due to the different opinions, morals, values, and interests of internal and internal stakeholders. Consequently, by promoting a collaboration culture among external and internal stakeholders and organizational commitment to satisfy the criteria of sustainability will gradually build a competitive advantage over other companies. In this context, one may take advantage of "stakeholder theory" [64, 65] when managing diverse stakeholders' opinions and values.

5. Concluding Remarks

The survival of modern societies and our shared planet depends on a more sustainable world. The present situation of the unsustainable world will eventually lead to climate change, health risks, depletion of unrenewable resources, conflicts, poverty, enormous inequalities, and social and economic instability. In this context, the sustainable development of construction logistic practices becomes an important issue because they can significantly improve environmental, economic, and social systems and satisfaction of urban stakeholders.

This study investigates the sustainable development of construction logistics from the perspective of a theoretical qualitative approach. General indicators and criteria of sustainability are developed to be integrated with the CLP and used as a basis for benchmarking and orientation management of urban stakeholders of construction projects. This integration is thought to be important to improve the sustainable development of construction logistic practices and provide a solid foundation for enhancing the potential for innovation in construction logistic practices.

The criteria of sustainable construction logistics generally represent central milestones of sustainability. By following the development of a criterion over time and assess the development quantitatively or qualitatively, project managers can control the level of sustainable development of the logistic operations of construction sites. To effectively plan for sustainability, these criteria need to be carefully considered in the CLP. This can help in tracking changes in environmental, social, and economic conditions affecting the logistic operations of the construction projects and in making construction companies more adaptable to hidden factors and unexpected problems related to sustainability.

Benchmarking and orientation management are two management tools that can enhance the re-engineering of logistic practices toward sustainability. Benchmarking can open construction companies to new sustainability methods, ideas, and tools to continuously improve their effectiveness.

Orientation management of stakeholders will lead to increased awareness among stakeholders and project actors, improving logistic operations throughout the supply chain to create an efficient organization focused on sustainable development. Subsequently, the cooperation of the external and internal stakeholders of the construction project can also result in the adoption of innovative government policies aiming at consolidating the sustainable development of construction logistics. It is noteworthy to indicate that the effective cooperation and engagement of all urban stakeholders may help in advancing new approaches and practices to minimize the adverse impacts of construction logistic operations on the environment, society and economy. Consequently, ignoring a stakeholder may have an adverse impact on the successful implementation of construction projects both in the long and short terms.

The three key indicators of sustainability, namely, environmental, societal, and economic indicators, are closely related to each other and all affect each other. The negative and positive impacts of the criteria of one indicator will affect the other criteria of the indicators. Consequently, the sustainable development of construction logistics will imply advancing synergic methods and measures to minimize the interrelated adverse impacts of all indicators.

In future studies, it is interesting to explore new perspectives, such as the impact of emerging technologies (AI and blockchain) on sustainable logistics. In addition, the implications for teaching, public policy, and commercial impact on the logistics practices in urban construction projects may be addressed to have a broader societal and academic analysis. In this context, the potential to influence public policy, especially through stakeholder orientation and sustainability planning, can further be developed.

Ethical Statement

This study does not contain any studies with human or animal subjects performed by the author.

Conflicts of Interest

The author declares that he has no conflicts of interest to this work.

Data Availability Statement

Data sharing is not applicable to this article as no new data were created or analyzed in this study.

Author Contribution Statement

Osama A. B. Hassan: Conceptualization, Methodology, Validation, Formal analysis, Investigation, Resources, Data curation, Writing – original draft, Writing – review & editing, Visualization, Supervision, Project administration.

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How to Cite: Hassan, O. A. B. (2025). Sustainable Construction Logistics, Part 1: A Theoretical Research Approach. *Green and Low-Carbon Economy*. https://doi.org/10.47852/bonviewGLCE52026301