



AUTOMATED EXTRACTION AND ANALYSIS OF GREENHOUSE GAS EMISSIONS IN CANADIAN CONSTRUCTION PROJECT PROCUREMENT

Y. Wu¹, D. Sobh¹, N.S. Gulemye¹, A. Sanchez Aguirre¹, A. Hammad¹, V. Gonzalez-Moret¹, and F. Hamzeh¹

¹ Department of Civil and Environmental Engineering, University of Alberta, Edmonton, AB, Canada

ABSTRACT: The construction industry accounts for 37% of global emissions in 2022, mainly from the production and transportation of materials, making it a critical contributor to greenhouse gas (GHG) emissions. Green Supply Chain Management (GSCM) offers principles to reduce emissions and improve sustainability across the supply chain. Yet, the industry faces barriers in adopting these principles due to the lack of accessible, user-friendly, and standardized tools that can effectively integrate and visualize sustainability indicators for procurement. Existing tools have limitations such as narrowed functionalities, lack of comprehensive data, and limited accessibility. This paper aims to facilitate GSCM by introducing the Green Supplier Selection Tool (GSST), a web-based application incorporated with AI automatic data extraction and analysis. The GSST allows users to identify suppliers based on certification (ISO 14001, BCorp, and LEED), calculate and compare Embodied Carbon Factor (ECF) across different materials and transportation modes, and automatically extract and summarize key emission data from Environmental Product Declaration (EPD) files. Moreover, the tool includes an interactive map that allows users to compare suppliers based on transportation modes, material quantity, and suppliers' emission levels while comparing emission thresholds. Initial results demonstrate the application's potential in assisting stakeholders in a deeper understanding of the sustainability implications of procurement choices through interactive, dynamic and integrated visualizations. The tool aims to raise awareness among stakeholders on procurement-related environmental impact. Further, it contributes to the reduction of the carbon footprint in the construction industry and supports global climate goals.

1. INTRODUCTION

Climate change is a global challenge, and the reduction of greenhouse gas (GHG) emissions is urgently needed on a global scale. Governments worldwide are adopting initiatives and collaborating to address greenhouse gas (GHG) emissions reduction. Including the Paris Agreement, which aims to limit global warming to below 1.5 degrees Celsius by 2030 (United Nations, 2015), and the Sustainable Development Goals (SDGs), an initiative by the United Nations which promotes sustainability across all sectors of the economy (United Nations, 2015). Construction is particularly relevant to addressing the global response to climate change.

The construction industry is one of the major contributors to climate change due to the extensive use of materials, energy, and transportation. The increasing demand for new infrastructure has shown the industry's significant impact on the environment, emphasizing the need for greater responsibility in

mitigating its effects (Mehra et al. 2021). One of the main reasons why the industry has such a large impact on the environment is the use of large supply chains. These supply chains result in a substantial carbon footprint through material production and transportation (Ouassou et al. 2024).

To address the challenge of carbon footprint, Green Supply Chain Management (GSCM) has emerged as an option that integrates environmental considerations into an already established area of management, namely supply chain management. It emphasizes practices such as zero waste, efficient use of resources, and the reduction of GHG emissions during the entire life cycle of goods and materials (Rupa & Mohammad Saif, 2021). Even though multiple industries have incorporated GSCM principles, such as manufacturing and retail, its application in the construction industry remains underdeveloped, despite its potential to significantly reduce emissions (Mojumder & Singh, 2021).

Due to the construction industry's scale and complex web of suppliers, it is suggested that GSCM adoption might be an important step in reducing the environmental footprint of construction projects. By optimizing the procurement processes and prioritizing sustainability, the construction industry would contribute to global efforts aimed at achieving net-zero emissions (Badi & Murtagh, 2019). Having gained popularity, there is now great interest in GSCM to reduce GHG emissions within the procurement and transportation of materials, which contributes to a significant share of the industry's overall emissions (Dzikriansyah et al. 2023). Estimates indicate that the construction sector accounts for approximately 25% of global CO₂ emissions, mainly resulting from the supply chain, particularly from heavy transport and the production of carbon-intensive materials as steel and cement (Karlsson et al., 2020)

This paper introduces the Green Supplier Selection Tool, a web-based application designed to integrate GSCM principles into construction procurement. The tool assists stakeholders in: 1) choosing sustainable suppliers according to certifications including ISO 14001, B Corp and LEED, 2) estimating embodied carbon using the Embodied Carbon Framework (ECF) Calculator, 3) performing material-specific emission analysis using an Environmental Product Declaration (EPD) Calculator; and 4) visually compare suppliers based on transportation modes, material quantity, and suppliers' emission levels using an interactive map.

2. PROBLEM IDENTIFICATION

The construction industry is one of the largest contributors to GHG emissions and therefore negatively affects the environment. According to Hong et al. (2015), the construction industry plays an important role in global warming, being the main contributor to global GHG emissions. The carbon dioxide emission from construction and building operations in 2022 accounted for 37% of the global CO₂ emissions, which was the highest on record to date (United Nations Environment Programme, 2023). Moreover, according to the World Green Building Council (2019), the construction of buildings is responsible for 11% of global carbon emissions, which makes it a critical component in the response to the climate emergency. In this regard, the industry has an urgent need to reduce these emissions.

The construction industry includes many processes that contribute to GHG emissions and negatively affect the environment, most of which originate from the production and transportation of materials sectors (Xu et al. 2020). Up to 70% of emissions caused by public procurement are attributed to six industries with construction being one of them (World Economic Forum, 2022). Hence, the construction industry faces increasing pressure to tackle the elevated greenhouse gas emissions associated with it and move towards low-carbon operations, particularly focusing on its procurement processes, including the transportation of materials.

Despite the presence of green practices in the construction industry, there are many challenges. Naniek et al. (2021) compiled multiple barriers which include a lack of awareness, a shortage of green professionals, a shortage of green suppliers, tight deadlines, high implementation cost, and lack of stakeholder collaboration. Moreover, environmental certifications, such as the ISO 14001, do not always influence supplier selection, and companies that acquire them are more interested in the image of having it rather than their actual impact on the environment (Jiang and Bansal, 2013). Additionally, Hammouri et al. (2011), stated that construction-specific carbon footprint calculators are limited.

Based on the challenges presented, we are proposing a visualization selection tool that assists stakeholders in sustainable supplier selection which would in return pave the path for sustainable procurement in the construction industry.

3. LITERATURE REVIEW

3.1 GHG Emissions

The World Resources Institute (WRI) and World Business Council for Sustainable Development (WBCSD) formed a joint initiative called Greenhouse Gas Protocol, which provides companies with standards to monitor GHG emissions in their operation and value chains (WRI and WBCSD, 2004). WRI and WBCSD (2004) grouped GHG emissions into Scope 1, Scope 2, and Scope 3.

In a construction project, Scope 1 GHG emissions are direct emissions from facilities owned or controlled by the company (WBCSD and WRI, 2004; API, 2021), including fuel combustion from on-site equipment and company-owned or operated vehicles. Scope 2 GHG emissions are indirect emissions produced during the production of the electricity purchased by a company for use on a construction project (WBCSD and WRI, 2004). Whereas Scope 3 emissions are indirect emissions generated during the manufacturing of the materials supplied in the construction project.

Of the primary greenhouse gases-water vapor, carbon dioxide, methane, nitrous oxide, and ozone-carbon dioxide are the most produced by the construction sector (Easterbrook, 2016). According to the United Nations Environment Programme (2023), the buildings sector is responsible for the largest percentage (37%) of greenhouse gas emissions, through the production and use of materials like steel, cement, and aluminum. This shows that key stakeholders such as owner, architect, engineer, and constructors – need to focus on upstream stages, including the selection of materials and procurement methods, to effectively reduce GHG emissions in construction projects.

While the best way to reduce this percentage is through selecting low carbon materials for construction right from the design phase, green supply chain management in construction procurement is another effective way to reduce emissions.

3.2 Green Supply Chain Management (GSCM)

Sarkis et al. (2011) define GSCM as the incorporation of environmental considerations into supply chain practices across organizations, including reverse logistics. In the construction industry, GSCM involves green practices that help to minimize environmental impacts. The key green practices identified in the construction supply chain include environmental impact assessment, green design, green purchasing, green transportation, green construction (for contractors), green manufacturing (for suppliers) and end-of-life management (Balasubramanian and Shukla 2017).

To effectively implement GSCM and gain a competitive advantage, contractors should choose their suppliers based on accurate knowledge of the suppliers' environmental capabilities and engage in close collaboration with them (Kim et al. 2016).

3.3 Criteria for Choosing Suppliers in GSCM

An essential aspect of supplier selection in GSCM is ensuring that suppliers meet environmental standards. (Balasubramanian and Shukla 2017) found that both contractors and suppliers utilize environmental standards like Environmental Management System (EMS), International Organisation for Standardization (ISO 14001 certification) and LEED to facilitate green practices in GSCM.

Additionally, it is significant to consider the distance of the supplier from the construction site (Ng et al., 2012). (Yan et al. 2010) in their case study, found that 6-8% of GHG emissions are from transportation of building materials on site. These emissions can be reduced by using transportation strategies such as “full-truck quantities and fuel-efficient vehicles” (Ng et al., 2012; Balasubramanian et al., 2017).

Silva et al. (2022) found from their literature analysis that the environmental criteria used by contractors to evaluate suppliers include eco-design, pollution control, environmental management system, use of ecological materials, resource consumption, strategic alliance and manager commitment to GSCM. The most significant environmental criteria for contractors when picking suppliers are eco-design, green certifications and green waste reclamation. A supplier that uses eco-design, government-certified materials and effective waste management has achieved the highest level of environmental sustainability (Asaad and El-Sayegh, 2021).

The literature mentioned above shows that the three significant environmental criteria for selecting suppliers include supplier information, material choices, and transportation information. A contractor should evaluate supplier information related to environmental aspects such as whether they have Environmental Management System (EMS) and Green Certifications. Additionally, the contractor should ensure that the supplier engages in environmentally friendly practices, such as using recycled materials and green energy (e.g., hydroelectricity) in the production of materials. Finally, the contractor should assess the GHG emissions from transportation of the construction materials.

3.4 Review of Supplier GHG Emissions Assessment Tools

To provide context on the current landscape and highlight existing capabilities and gaps that motivate our work, Table 1 summarizes several available tools used for assessing supplier GHG emissions, outlining their key features and notable limitations. Some of which are represented in Table 1.

Table 1. Assessment Tools for Supplier GHG Emissions

Name	Description	Limitations
Embodied Carbon in Construction Calculator (EC3)	A free tool that allows contractors to benchmark and evaluate suppliers based on their carbon emissions	It does not directly calculate the ideal transportation route for suppliers to minimize emissions.
Sphera	A sustainability management platform that allows companies to evaluate suppliers' sustainability	Suppliers are given scores for multiple criteria, however it does not provide data on GHG emissions. Also, most of the analytics features are available for a fee.
GHG Protocol Tools	International accounting tools that help businesses measure their GHG emissions	These tools are not specific to the construction industry, require knowledge on emission calculations, and require manual collection and input of suppliers' emissions.
Oracle Enterprise Resource Planning (ERP)	A software that focuses on the management of multiple functions in an organization, one of which is helping assess potential suppliers based on their environmental efforts and sustainability practices	It is a comprehensive tool used for various business functions in many industries. Despite facilitating supplier management, it does not provide actual ranking of suppliers based on GHG emissions.
Carbon Disclosure Project (CDP)	A non-governmental organization that encourages companies to disclose their environmental impact	The platform is not exclusive to suppliers in the construction industries. Moreover, it ranks companies on multiple criteria and gives them a letter grade.
Greenhouse Gas Reporting Program (GHGRP)	A tool that enables users to access GHG emissions data reported by facilities across Canada	Exclusive to Canada and lists companies from different industries.

Despite the different tools available that would help contractors assess and rank suppliers, they do not fully encompass or integrate multiple areas critical for comprehensive sustainable procurement across the supply chain. For instance, some tools are too broad and target many different functions across multiple

industries, such as general GHG Protocol Tools or CDP, lacking construction-specific focus. Others may provide only high-level assessments, such as a letter ranking, without detailed information on actual GHG emissions or the ability to link qualitative certifications (e.g., ISO 14001) with quantitative supplier performance data. Moreover, many tools do not incorporate the ability to effectively compare emissions based on material choices, transportation modes and distances within a single interface, or they lack features for automated analysis and comparison of detailed Environmental Product Declaration (EPD) data across multiple suppliers. Access to more advanced analytical features on some platforms is also sometimes restricted to premium users.

4. RESEARCH GAPS

This study identifies three research gaps in the context of greenhouse gas (GHG) emissions and Green Supply Chain Management (GSCM) within the construction industry, as follows:

(1) *Lack of Construction-Specific Tools for Comprehensive GHG Emissions Assessment.* Existing tools, such as the GHG Protocol Tools and the Embodied Carbon in Construction Calculator (EC3), are either not tailored to the construction industry or fail to integrate emissions data across material production, transportation, and supplier performance, limiting their effectiveness in holistically addressing construction-related GHG emissions.

(2) *Limited Adoption of GSCM Practices in Construction.* Despite GSCM's potential to reduce emissions through sustainable supplier selection, green purchasing, and efficient transportation, its application in construction is hindered by barriers such as lack of awareness, insufficient green suppliers, and a lack of user-friendly decision-support tools, impeding sustainable procurement practices.

(3) *Inadequate Visualization and Comparison of Supplier and Transportation Emissions.* Current tools lack dynamic, interactive visualization capabilities to compare suppliers based on environmental certifications, material-specific emissions, and transportation modes, restricting stakeholders' ability to optimize procurement decisions and minimize the carbon footprint of construction projects.

5. METHODOLOGY

With all the gaps and state-of-the-arts discussed in previous sections, we developed a methodology flowchart (Figure 1) for the implementation of the application. The Green Supplier Selection Tool (GSST) is a web-based application using the MERN stack and AI to support sustainable construction procurement. It enables supplier selection by certifications, calculates embodied carbon, analyses EPDs, and visualizes transportation routes, aiming to reduce GHG emissions and enhance sustainability. Please refer to section 6 for more information about the application.

5.1 Phase 1: Preliminary Research

This phase involved defining the scope of the study and identifying key parameters. The organization was defined as the main user of the GSST, including teams and individuals involved in procurement, project management, and sustainability. The study focused on suppliers relevant to the organization's assessment interests, considering factors like supplier tiering (Tier 1, Tier 2, etc.) and materiality (Figure 1).

5.2 Phase 2: Data Collection

Criteria were established for selecting suppliers to include in the analysis. These criteria included supplier type, environmental impact (assessed through certifications and emission standards), data availability (online sources, EPDs, location data), and the use of materials and transportation information. To ensure comprehensive analysis, all suppliers were included rather than focusing on specific lifecycle stages. Data was collected from various sources, including online databases, EPDs, and supplier websites. An AI model (gpt-4o) was utilized to assist in extracting certification information from diverse web sources (Figure 1).

5.3 Phase 3: Data Processing & Analysis

Embodied carbon factors (ECF) and environmental product declaration (EPD) are two sources provide quantitative information on the environmental impacts associated with a material product's life cycle (The Institution of Structural Engineers, 2023; Canadian Steel Sheet Building Institute, 2022). The ECF quantifies greenhouse gas emissions, primarily carbon dioxide, while EPDs provide a broader set of standards based on ISO 14025. Both indices include environmental information in material production, construction, operation and maintenance, and end-of-life management phases (Figure 2). This study primarily focuses on the material production and construction stages by the availability of high-quality, standardized data, such as EPDs, which are essential for accurate embodied carbon and environmental impact assessments. Various environmental indicators were derived from the EPD files, with their definitions can be found in Table II. A pre-trained form parser model was used to efficiently extract relevant information from the EPD files.

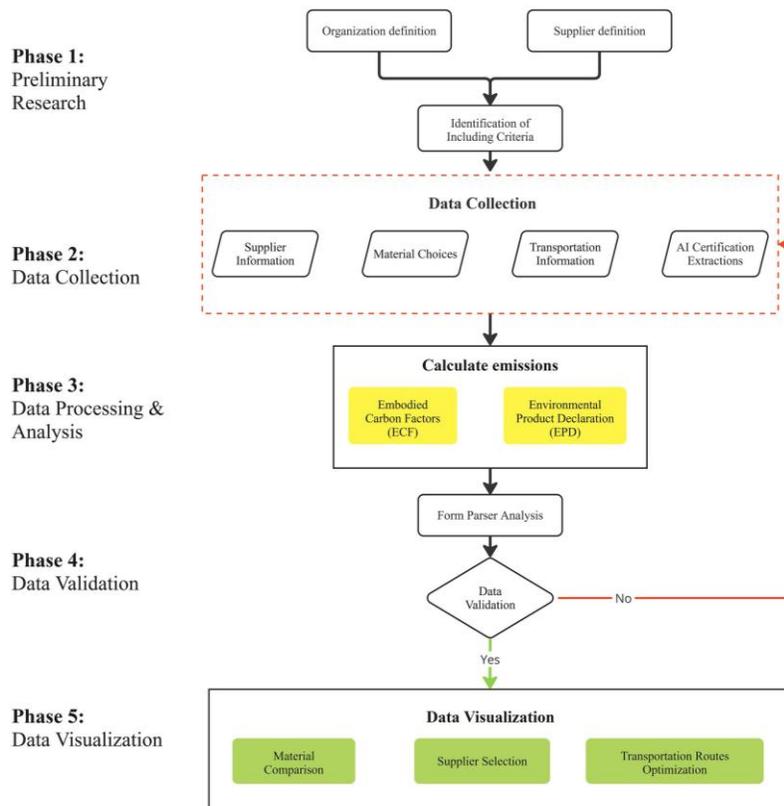


Figure 1. A Flowchart of Methodology

Emissions in Different Stages of Life Cycle															
Stages	Material Production			Construction			Operation & Maintenance					End-of-Life			
	A1	A2	A3	A4	A5w	A5a	B1	B2	B3	B4	B5	C1	C2	C3	C4
Modules	Raw Material Extraction	Material Transport to Manufacturing	Product Manufacturing	Transport to Construction Site	Construction & Installation - Material Waste	Construction & Installation - Site Activities	Building Use	Maintenance	Repair	Replacement	Refurbishment	Deconstruction	Transport of waste/materials	Waste Processing	Disposal
Approximate Distribution	50%			4%	1%		20%		23%			2%			

Figure 2. Emissions in Different Lifecycle Stages

Notes. Adapted from “A brief guide to calculating embodied carbon” by *The Institution of Structural Engineers*, 2020

Table 2. Environmental Impact Indicators in an EPD life cycle assessment (*Environmental Performance Indicators | EPD International*, retrieved on Nov 28, 2024)

Name	Acronym	Description
Global Warming Potential	GWP/ GWP100	Measures a substance's contribution to climate change. The higher the GWP, the more it warms the planet.
Acidification Potential	AP	Measures a substance's contribution to acid rain and the acidification of soil and water. The higher the AP, the more compounds are released to form acids in the atmosphere.
Eutrophication Potential	EP	Measures how much a substance contributes to excessive algae growth in water by increasing nutrient levels. The higher the EP, the more algae grow, potentially harming aquatic life.
Photochemical Ozone Creation Potential	POCP	Measures how much a substance contributes to the formation of ground-level ozone (smog) through chemical reactions in the atmosphere. The higher the POCP, the more smog it creates.
Abiotic Depletion Potential	ADP	Measures how much a substance contributes to the depletion of non-renewable resources like minerals and fossil fuels. The higher the ADP, the faster these resources are depleted.
Water Deprivation Potential	WDP	Measures how much a substance or activity contributes to water scarcity in a region by consuming or polluting water sources. The higher the WDP, the more it contributes to water shortages.

5.4 Phase 4: Data Validation

A two-stage validation process was implemented to ensure the GSST's reliability and usability. First, the research team simulated real-world scenarios, taking on roles like "procurement manager" and "sustainability consultant" to test the tool's functionality with various material choices, transportation options, and project scales. Second, an in-class demonstration with students from diverse disciplines provided feedback on the tool's interface and visualizations, ensuring clarity and accessibility for a broader audience.

5.5 Phase 5: Data Visualization

The collected and analyzed data was visualized through an interactive web-based application. This application features tables and maps that allow stakeholders to explore different scenarios, compare material and supplier options, and optimize transportation routes. Color-coding and visual cues highlight key environmental indicators, facilitating a deeper understanding of the environmental impacts associated with various choices.

6. DEVELOPMENT OF THE APPLICATION

The Green Supplier Selection Tool (GSST) is a web-based application developed using the MERN stack, a popular combination of technologies that benefits from a comprehensive ecosystem of JavaScript tools and libraries throughout the application. The selection of React (for MERN) over Angular (for MEAN) was primarily driven by React's flexible component-based architecture, which facilitated efficient development of the interactive user interface components required for the GSST. A brief definition of the technical stacks is as below:

- **MongoDB:** A NoSQL database that provides a flexible and scalable solution for storing and managing the application's data, including supplier information, material data, and user inputs.
- **Express.js:** A back-end web application framework for Node.js that simplifies the development of APIs and server-side logic, handling routing, requests, and responses. Within this structure, API routes are typically defined using modules like `express.Router()`, mapping HTTP methods to specific controller functions. These controllers then orchestrate the interaction with the MongoDB database, often utilizing Mongoose models to query or update data based on the logic required for the incoming request.

- React: A JavaScript library used to build the user interface (UI) of the application. Its component-based architecture allows for efficient development and a dynamic and interactive user experience.
- Node.js: A JavaScript runtime environment that executes JavaScript code outside of a web browser, enabling server-side scripting and back-end functionality.

The choice of technology stack was driven by the desire for a unified language (JavaScript) across the entire application, facilitating efficient development and maintenance. The Express.js framework was selected for its lightweight, JavaScript-based ecosystem, aligning with our MERN stack and team expertise. While .NET offers performance benefits, Express.js sufficiently met GSST's performance requirements. The application's development was spearheaded by an experienced software engineer within the research team, with collaborative input and testing from other members who assumed the roles of various stakeholders, such as procurement managers and sustainability consultants. This collaborative approach ensured the tool's functionality aligned with real-world user needs and industry practices.

Other than the libraries provided by MERN, the GSST also used three main Application Programming Interface (API) to provide its core functionalities, such that a gpt-4o model provided by open AI, a customized form phaser algorithm trained by the researchers, and a google map API:

- GPT-4O (gpt-4o | Open AI): This powerful language model from OpenAI was employed for tasks including analyzing different website content to identify companies with specific certifications, including ISO 14001, B Corp, LEED and extracting relevant information from unstructured data sources. This automated data extraction significantly streamlined the process of building comprehensive databases for the application.
- Custom Form Parser Algorithm (pretrained-form-parser-v2.0-2022-11-10, pretrained-foundation-model-v1.3-2024-08-31 | Document AI | Google Cloud): To efficiently process and analyze Environmental Product Declarations (EPDs), the application utilizes a custom form parser algorithm trained by the researchers. This algorithm builds upon Google Document AI's pre-trained form parser models, adding a layer of customization to accurately identify and extract key environmental indicators from EPDs, enabling automated analysis and comparison of materials.
- Google Maps API: The Routes Tab offers an interactive mapping interface with the help of Google Maps API. This allows users to visualize and compare different transportation routes based on material quantity, transport mode, and supplier emissions, with color-coded markers indicating emission thresholds.

The application's front-end interface, built with React, provides users with an intuitive and user-friendly experience. It features four mains features, as in Table 3.

Table 3. An Overview of GSST's Features

Feature	Description	Contribution to GSCM	Figure
Supplier Database	Search and filter suppliers by certifications (e.g., ISO 14001, B Corp, LEED) and location.	Enables selection of certified suppliers, promoting sustainable sourcing practices.	Figure 3
ECF Calculator	Calculate embodied carbon for materials based on type, quantity, transport mode, and distance.	Supports low-carbon material choices, aiding compliance with net-zero goals.	Figure 4
EPD Calculator	Upload EPD PDFs to extract environmental indicators (e.g., GWP, AP) automatically.	Enhances transparency in material impact assessment, streamlining comparisons.	Figure 5
Routes	Visualize transport routes by material quantity, mode, and emissions via an interactive map.	Optimizes logistics to minimize GHG emissions, aligning with green supply chain principles.	Figure 6

Green Supplier Selection Tool

Supplier Selection ECF Calculator EPD Calculator Routes

Search by company name ISO 14001 BCorp LEED

Company Name ▼	ISO 14001	BCorp	LEED
Teknion Roy & Breton Inc. - Head Office	Yes	No	No
Teknion Roy & Breton Inc. - Logistic and Client Service Centre	Yes	No	No
Teknion Roy & Breton Inc. - RB Tek	Yes	No	No
Teknion Roy & Breton Inc. - Roy & Breton	Yes	No	No
Teknion Roy & Breton Inc. - Teknion Concept	Yes	No	No
Teknion Roy & Breton Inc. - Teknion LS	Yes	No	No
Teknion Roy & Breton Inc. - Teknion Québec	Yes	No	No
Teknion Roy & Breton Inc. - Client Service Centre	Yes	No	No
Scott Construction Group	No	Yes	Yes
Trico Homes	No	Yes	No
Rise	No	Yes	Yes
Chandos Construction	No	Yes	Yes
Sky Fire Energy	No	Yes	No

Figure 3. A Snapshot of the Supplier Selection Tab

Concrete - In situ

Unreinforced, C30/37, UK average ready-mixed concrete EPD (35% cement replacement)

Unreinforced, C32/40, 25% GGBS cement replacement

Unreinforced, C32/40, 50% GGBS cement replacement

Unreinforced, C32/40, 75% GGBS cement replacement

Unreinforced, C40/50, 25% GGBS cement replacement

Unreinforced, C40/50, 50% GGBS cement replacement

Unreinforced, C40/50, 75% GGBS cement replacement

Concrete - Precast

Unreinforced, C40/50 with average UK cement mix

Reinforced, 150mm prestressed hollow core slab: British Precast Concrete Federation average EPD

Steel - Reinforcement Bars

UK: BRC EPD

Worldwide: Worldsteel LCI study data, 2018, world average

Steel - I/F Sections

(Assume the same as reinforcement bars)

Steel - Structural Sections

UK open sections: British Steel EPD

Europe (excl. UK): Bauforumstahl average EPD

Worldwide: Worldsteel LCI study data, 2018, world average

Embodied carbon per material

A1-A3 (Production): 5.15 kgCO₂e

A4 (Transport): 40.35 kgCO₂e

WF (Waste Factor): 5.30

C2 (Recycling Transport): 0.25 kgCO₂e/kg

C3-C4 (End-of-Life): 0.01 kgCO₂e/kg

A5w (Waste Emissions): 2.43 kgCO₂e

Embodied carbon per material: 47.93 kgCO₂e

Comparison Table

Material	A1-A3	A4	A5w	Total Emissions
concrete_in_situ_unreinforced_c30_37_uk_avg	5.15 kgCO ₂ e	40.35 kgCO ₂ e	2.43 kgCO ₂ e	47.93 kgCO ₂ e
concrete_in_situ_unreinforced_c40_50_25_ggbs	6.90 kgCO ₂ e	1498.58 kgCO ₂ e	79.80 kgCO ₂ e	1585.28 kgCO ₂ e

Figure 4. Snapshots of the ECF Calculator Tab

Company: Lazzon Hardwood Flooring

Material 1: Solid Construction Flooring Material 2: 3/18 Engineered Construction Flooring Material 3: Solid 2-Ply Engineered Construction Flooring

Solid Construction Flooring				
Environmental Impact	Unit	Total	Production	Transportation to Site
Global Warming Potential (GWP)	kg CO2 eq	15.1	7.55	1.13
Biogenic Carbon Removals (BCR)	kg CO2	-43	41	-0.05
Biogenic Carbon Emissions (BCE)	kg CO2	17	14.8	0
Ozone Depletion Potential (ODP)	kg CFC-11 eq	0.00000165	8.26e-7	4.96e-8
Acidification Potential (AP)	kg SO2 eq	0.119	0.0715	0.00866
Eutrophication Potential (EP)	kg N eq	0.178	0.0028	0.000338
Smog Formation Potential (SFP)	kg O3 eq	2.5	1.84	0.216
Abiotic Resource Depletion Potential (ADP)	MJ surplus	28.8	12.1	2.35

3/18 Engineered Construction Flooring				
Environmental Impact	Unit	Total	Production	Transportation to Site
Global Warming Potential (GWP)	kg CO2 eq	13.1	6.85	0.885
Biogenic Carbon Removals (BCR)	kg CO2	-22.4	-21.3	0
Biogenic Carbon Emissions (BCE)	kg CO2	8.26	7.34	0
Ozone Depletion Potential (ODP)	kg CFC-11 eq	0.00000161	8.4e-7	2.11e-8
Acidification Potential (AP)	kg SO2 eq	0.095	0.093	0.000356
Eutrophication Potential (EP)	kg N eq	0.131	0.028	0.000176
Smog Formation Potential (SFP)	kg O3 eq	1.72	1.24	0.113

Figure 5. Snapshots of the EPD Calculator Tab

Routes

Select Transport Mode: Road

Quantity (kg): 4000

Companies by Emission Level

Chandos Construction - 6.56 kgCO₂e (15.41 km)

Sky Fire Energy - 113.28 kgCO₂e (287.22 km)

Trico Homes - 117.94 kgCO₂e (276.86 km)

Scott Construction Group - 537.82 kgCO₂e (783.01 km)

Teknion Roy & Breton Inc. - Teknion LS - 1205.38 kgCO₂e (3345.52 km)

Teknion Roy & Breton Inc. - Head Office - 1305.99 kgCO₂e (3065.71 km)

Teknion Roy & Breton Inc. - Logistic and Client Service Centre - 1305.99 kgCO₂e (3065.71 km)

Teknion Roy & Breton Inc. - Client Service Centre - 1305.99 kgCO₂e (3065.71 km)

Teknion Roy & Breton Inc. - RB Tek - 1306.68 kgCO₂e (3067.27 km)

Teknion Roy & Breton Inc. - Roy & Breton - 1315.44 kgCO₂e (3076.18 km)

Teknion Roy & Breton Inc. - Teknion Québec - 1319.21 kgCO₂e (3086.74 km)

Rise - 1443.05 kgCO₂e (3419.97 km)

Figure 6. Snapshots of the Routes Tab

The application's back-end infrastructure is designed to efficiently handle data processing, calculations, and API interactions. It ensures a seamless user experience with fast response times and reliable performance. The development process involved rigorous testing and validation to ensure the accuracy, usability, and relevance of the tool for a diverse range of stakeholders in the construction industry.

The custom form parser algorithm processes EPD PDFs as follows: (1) **Parsing**: Converts the PDF into a machine-readable format using layout analysis. (2) **Section Identification**: Fine-tuned on 50 annotated EPDs, it identifies life cycle assessment (LCA) tables by detecting patterns like “GWP”, “AP”, and “kg CO₂-eq” using Google Document AI’s text classification. (3) **Extraction**: Extracts values and units (e.g., 150.5 kg CO₂-eq) into a JSON object. (4) **Visualization**: Displays data in the React front-end (Figure 5) for material comparisons. Further, the Google Maps API was integrated into the Green Supplier Selection Tool (GSST) using the `@react-google-maps/api` library within the React-based MERN stack application. Following the Google Maps Platform documentation, a map component was implemented to display an interactive interface in the Routes tab. The API enables visualization of supplier locations with color-coded markers representing emission thresholds based on material quantity and transport mode.

7. ACADEMIC AND INDUSTRIAL CONTRIBUTIONS

There are several GCSM tools that currently exist; however, none fully address the sustainability challenges of the construction industry. The slow adoption of GSCM could be due the lack of a comprehensive tool to support GSCM decision making. This study contributes to academia and industry by introducing a free user-friendly application that facilitates sustainable procurement decisions. Academically, this study contributes by introducing the integrated GSST platform that serves as a potential solution of identified limitations of the existing supplier assessment tools and providing a foundation and opportunity for further studies in GSCM. As for the industry, this application provides practical benefits such as facilitating sustainable design by enabling engineers and designers to compare the embodied carbon across different materials, selecting sustainable suppliers, and reducing GHG emissions caused by transportation.

8. CONCLUSION

In this paper, the authors introduced a comprehensive web-based green supplier selection tool that aims to contribute to reducing the carbon footprint of construction projects. The application enables users to evaluate suppliers based on different certifications, analyze and compare embodied carbon across different materials, quantities, and transportation routes, as well as perform automated data extraction and analysis of EPD files. Adopting this tool across the construction industry will support the industry’s transition toward more sustainable operations and align with global climate goals.

While the tool provides valuable insights, it includes limitations as it is currently in the demo stage and the database of suppliers available is limited, it is restricted to two stages of the Building Life Cycle, and it is not dynamic to real changes to transportation and market conditions. Moreover, for this tool to be adopted broadly, it requires incentives and legal mandates to motivate users. To address these limitations, future enhancements include expanding the database, testing the tool with real-life contractors and integrating their feedback, as well as incorporating Life Cycle Cost Analysis to evaluate both environmental and financial impacts. To further validate the tool's reliability and AI accuracy, future work will include real-world pilot studies. Additionally, future development could explore methods for incorporating real-time transportation and market data, as well as data from construction, installation, and end-of-life stages, as standardized data becomes more readily available. This integration would enhance the tool's ability to provide a comprehensive and dynamic environmental impact assessment for construction projects.

REFERENCES

American Petroleum Institute, API. 2021. Compendium of Greenhouse Gas Emissions Methodologies for the Natural Gas and Oil Industry, American Petroleum Institute, Washington, DC, USA.

- Ammouri, A.H., Srour, I., & Hamade, R.F. 2011. Carbon Footprint Calculator for Construction Projects (CFCCP). *Advances in Sustainable Manufacturing: Proceedings of the 8th Global Conference on Sustainable Manufacturing*, Springer, Berlin Heidelberg, 327-331.
- Asaad, A., and El-Sayegh, S.M. 2021. Key Criteria for Selecting Green Suppliers for Construction Projects in the UAE. *Journal of Financial Management of Property and Construction*, 26 (2): 201-218.
- Badi, S., and Murtagh, N. 2019. Green Supply Chain Management in Construction: A Systematic Literature Review and Future Research Agenda. *Journal of Cleaner Production*, 223: 312–222.
- Balasubramanian, S., and Shukla, V. 2017. Green Supply Chain Management: An Empirical Investigation on the Construction Sector. *Supply Chain Management*, 22(1): 58-81.
- Balasubramanian, S., & and Shukla, V. 2017. Green supply chain management: the case of the construction sector in the United Arab Emirates (UAE). *Production planning & control*, 28(14), 1116–1138.
- Castro e Silva, A.D., Seleme, R., de Assis Silva, W., Zattar, I.C., Nara, E.O.B., Júnior, O.C., and Benitez, L.B. 2022. Evaluation and Choice Criteria of Sustainable Suppliers in the Construction Industry: A Comparative Study in Brazilian Companies. *Sustainability*, 14(23), 15711.
- Dzikriansyah, M.A., Masudin, I., Zulfikariyah, F., Jihadi, M., and Jatmiko, R.D. 2023. The Role of Green Supply Chain Management Practices on Environmental Performance: A Case of Indonesian Small and Medium Enterprises. *Cleaner Logistics and Supply Chain*, 6: 100100.
- Easterbrook, D.J. 2016. Greenhouse Gases. *Evidence-Based Climate Science*, Elsevier, 163–73.
- Hertwich, E.G., and Wood, R. 2018. The Growing Importance of Scope 3 Greenhouse Gas Emissions from Industry. *Environmental Research Letters*, 13 (10): 104013.
- Handayani, N.U., Wibowo, M.A., Rinawati, D.I., and Gabriella, T. 2021. Drivers and Barriers in the Adoption of Green Supply Chain Management in Construction Projects: A Case of Indonesia. *International Journal of Construction Supply Chain Management*, 11(2), 89-106.
- Hong, J., Shen, G.Q., Feng, Y., Lau, W.S.T., and Mao, C. 2015. Greenhouse Gas Emissions During the Construction Phase of a Building: A Case Study in China. *Journal of Cleaner Production*, 103, 249-259.
- Jiang, R.J., and Bansal, P. 2003. Seeing the Need for ISO 14001. *Journal of Management Studies*, 40(4), 1047-1067.
- Karlsson, I., Rootzén, J., and Johnsson, F. 2020. Reaching net-zero carbon emissions in construction supply chains: Analysis of a Swedish road construction project. *Renewable and Sustainable Energy Reviews*, 120: 109651
- Kim, K.T., and Kim, I. 2021. The Significance of Scope 3 GHG Emissions in Construction Projects in Korea: Using EIA and LCA. *Climate*, 9(2): 33.
- Kim, M.G., Woo, C., Rho, J.J., and Chung, Y. 2016. Environmental Capabilities of Suppliers for Green Supply Chain Management in Construction Projects: A Case Study in Korea. *Sustainability*, 8(1): 82.
- Mehra, S., Singh, M., Sharma, G., Kumar, S., Navishi, and Chadha, P. 2021. Impact of Construction Material on Environment. *Springer*, 427-442.
- Mojumder, A., and Singh, A. 2021. An Exploratory Study of the Adaptation of Green Supply Chain Management in Construction Industry: The Case of Indian Construction Companies. *Journal of Cleaner Production*, 295: 126400.
- Ng, S.T., Wong, J.M.W., Skitmore, S., and Veronika, A. 2012. Carbon Dioxide Reduction in the Building Life Cycle: A Critical Review. *Proceedings of the Institution of Civil Engineers: Engineering Sustainability* 165(4): 281-292.
- Ouassou, E. H., Onyeaka, H., Tamasiga, P., and Bakwena, M. 2024. Carbon Transparency in Global Supply Chains: The Mediating Role of Institutional and Innovative Capacity. *Energy Strategy Reviews*, 53: 101405.
- Pan, W., Dainty, A.R.J., and Gibb, A.G.F. 2012. Establishing and Weighting Decision Criteria for Building System Selection in Housing Construction. *Journal of Construction Engineering Management*, 138(11): 1239–1250.
- Sarkis, J., Zhu, Q., and Lai, K.H. 2011. An Organizational Theoretic Review of Green Supply Chain Management Literature. *International Journal of Production Economics*, 130(1): 1–15.
- Yan, H., Shen, Q., Fan, L. C. H., Wang, Y., and Zhang, L. (2010). Greenhouse gas emissions in building construction: A case study of One Peking in Hong Kong. *Building & Environment*, 45(4), 949–955.
- Xu, J., Huang, Y., Shi, Y., and Deng, Y. 2020. Supply Chain Management Approach for Greenhouse and Acidifying Gases Emission Reduction Towards Construction Materials Industry: A Case Study from China. *Journal of Cleaner Production*, 258: 120521.