

Web-based Simulation of Delivery Carbon Footprints for SMEs in Bangladesh: An Eco-friendly and Fuel Optimization Framework for Sustainable Growth

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Abstract

In Bangladesh, SMEs are inclined to use local routing information, frequent ad-hoc delivery rates, and poor usage of fuel, which makes their operations more expensive and produces more carbon emission. The vast majority of SMEs are not aware of such effects or have tools that are readily accessible to quantify or control their footprint as it relates to logistics. The paper creates a web-based simulation model that predicts the output of the CO₂ emissions that are vehicle-specific, as well as the distance covered, the type of vehicle, and the load consolidation, and the type of fuel, and the most sustainable and cost-effective interventions are determined. Sensibility analysis will be used to calculate the most sustainable and cost-effective interventions. The results show that the emission can be minimized with the optimal routing and loading consolidation, and further can be achieved through fuel switching and fuel efficiency. The suggested structure will help in achieving Sustainable Development Goal (SDG) 12, which engages in responsible use of resources and efficient operations, and SDG 13, which allows the SMEs to track, control, and reduce their carbon footprint. The proposed model can provide a solution to the digitalization of the logistics of SMEs in Bangladesh that could help to achieve sustainable development based on the planning that is information-driven and environmentally friendly.

Keywords

Carbon footprint, Web-based simulation, SMEs (Small and Medium Enterprises), Sustainable logistics, Fuel optimization, Route optimization, Eco-friendly transportation, CO₂ emissions reduction.

1. Introduction

In this developing economic landscape of Bangladesh, SMEs perform as the backbone of the economy by generating employment, driving innovation and supporting sustainable growth. However, their logistics operations, particularly last-mile delivery often rely on informal and inefficient practices (Sorooshian et al., 2022; Núñez-Merino et al., 2025). There is a strong dependence on localized, experimental routing, frequent unscheduled deliveries and inefficient fuel management, which lead to significant operational inefficiencies. These practices increase operational costs and generate a disproportionately high carbon footprint, yet most SMEs lack the tools or awareness needed to quantify this impact, as there is no affordable and easy to use tool exists to help businesses measure or reduce their delivery footprint (Sorooshian et al., 2022).

This inefficiency in practice is a twofold problem, as it contradicts the world goals of sustainable consumption and production Sustainable Development Goal 12 (SDG 12) directly (to create sustainable consumption and production patterns) and Sustainable Development Goal 13 (SDG 13), which requires an urgent response to the problem of climate change and its consequences (Babacan, 2024). This study fills this important gap by suggesting a useful, online simulation framework for small and medium-sized businesses (SMEs) in Bangladesh. The framework can allow users to support the modeling of their distribution networks, calculate the CO₂ emissions of their vehicles by type, distance, load, and fuel consumption and find cost-effective approaches to savings, including changing routes, or fuel types. The study will help SMEs to become more sustainable in their logistics with the help of an easy and convenient digital solution, which will have short-term positive effects on the environment and long-term economic sustainability.

This study, through this conveniently available digital tool, will allow SMEs to shift to more sustainable logistics solutions, and this will have a direct effect on environmental impact as well as economic flexibility in the future.

1.1 Objectives

- Develop a web-based application that enables SMEs to calculate their delivery carbon footprint.
- Analyze the impact of vehicle type, route distance, load consolidation and fuel type in CO₂ emissions.
- Use the simulation tool to identify practical and affordable strategies for reducing emissions for SME delivery operations.
- Provide recommendations based on SDG 12 and SDG 13 to help achieve sustainable and eco-friendly logistic operations.

2. Literature review

The major source of global carbon emissions is the logistics sector and its last mile delivery portion is especially problematic due to inherent inefficiencies (Sundarakani et al., 2010). In a developing country like Bangladesh, this issue is maximized. The rapid growth of Small and Medium Enterprises (SMEs), which dominate the economy, relies heavily on delivery networks that are often informal, unoptimized and unaware of their environmental impact. While the need for sustainable urban delivery load is recognized in policy circles (Labib et al., 2014) and studies confirm that green practices improve performance. Most SMEs simply do not have the tools or data to participate in this green transition (Johnson et al., 2016). This paper will attempt to bridge that gap by developing a web-based simulation tool that can enable Bangladeshi SMEs to visualize and minimize their delivery carbon footprint by smarter routing and fuel choices.

Even though current research offers a solid basis, it clearly leaves a practical gap. Several influential studies have established complex models for planning entire city logistics systems (Sundarakani et al., 2010). However, these models are for large scale planning and do not address the daily delivery decisions of individual SMEs. Recent developments in road transportation make it possible to predict vehicle CO₂ emissions, which can be incorporated into eco-routing systems (Zeng et al., 2016). Similarly, the technical possibility to reduce emissions is demonstrated through the reviews of the eco-friendly route planning algorithms (Fahmin et al., 2024). Nevertheless, these are still primarily theoretical rather than practical, useful tools designed for SMEs. The study clearly identifies carbon management as a strategic challenge for SMEs (Hendrichs & Busch, 2012) and confirms that SME carbon reduction initiatives can also act as a catalyst for green jobs and broader value creation (Olekanma et al., 2024). Despite this recognition, a shortage persists in software based tools that are both affordable and user-friendly for the SME sector (Johnson et al., 2016). Research has successfully documented the obstacles in Bangladesh. Studies highlight the chaotic traffic, the mixed vehicle types and the local SMEs logistics (Labib et al., 2014). Existing green practices, like better car maintenance and driver education, have been shown to improve operational performance in a number of

studies (Jabbar & Hossain, 2022). While these findings are valuable, the studies focus mainly on identifying the problems or outcomes and rather than proving practical solutions that SMEs can implement.

A significant step forward was made by Eleftheriadis & Anagnostopoulou (2024) with their tool that could calculate the overall carbon footprint of an SME. Similarly, Groschopf et al. (2019) developed a carbon-tracking tool focused on road transportation. This work shows significant steps toward practical implementation. Our study is based on their foundation but it also expands their approach by adding fuel optimization and cost-benefit analysis. This allows SMEs to observe both their carbon footprint and simulate alternative scenarios such as switching fuel types or adding loads and determine the strategies that maximize cost and reduce emissions. The inclusion of these layers makes our framework a usable web based tool that is specifically designed to suit the decision making of SME so as to create a gap between analysis and solution.

The importance of designing sustainability tools especially for SMEs is well established in the literature, which highlights a shortage of software that is both affordable and user-friendly (Johnson et al., 2016). Therefore, the design goal of this paper is to build a functional web application. It uses established principles for optimization, applies standard emission factors based on vehicle data and gives the results. Furthermore, it is an actual approach that enables SMEs to connect with sustainable development by showing clear co-benefits for both cost and carbon. In addition, the proposed research will provide a practical avenue through which SMEs can play a direct role in SDG 12 (Responsible Consumption) and SDG 13m (Climate Action), transforming the field of research to practical application.

3. Methodology

This part speaks about how to build, create, and utilize an online carbon footprint simulation tool just for small and medium-sized businesses (SMEs) in Bangladesh. The process includes designing the system, setting the input parameters, and creating the arithmetic that will be used to figure out costs and emissions.

3.1 System Architecture and Technology Stack

The simulation tool was developed as a client-side Single Page Application (SPA) to make sure it is as accessible as feasible and that the deployment cost won't be a major obstacle for resource-constrained SMEs in Bangladesh. The architecture ensures that all computing processes are done in the user's browser, thus there is no requirement for server space or concerns regarding confidentiality while the tasks are being done.

3.1.1 Implementation of Technology

The system is constructed using the following technological stack:

- Frontend Framework: The user interface will be built using react.js (version 18+).
- Animation Library: Use Framer Motion in order to render the process easier for users and make the transition smoother.
- Logic Buildup: Modular architecture for maintainability using only JavaScript (ES6+).
- Data visualization: Chart.js allows comparative scenario analysis and sees the data in a graph.
- Logic Buildup: The system's logic is implemented with a modular design using JavaScript (ES6+), promoting maintainability and scalability.

This technology was developed for three reasons: (i) it works with a wide range of desktop and mobile platforms; (ii) it is easy to set up with regular web hosting; and (iii) its open source code makes it possible to replicate and study.

3.1.2 Architecture of System Flow

The three-layer design serves as the foundation for the simulation workflow:

Layer 1: Interface for User Input

- A form collects the following parameters:
- Starting point and destination (for route contextualization)
- Type of vehicle
- Type of fuel
- Weight of cargo load in kilos
- The quantity of delivery journeys
- capacity of a vehicle

Layer 2: Calculation and Processing Engine

Five consecutive procedures are carried out by the basic computational module (calculations.js):

- As a part of the standard data tables, determining the capacity, fuel expenses, emissions, and efficiency of the vehicle.
- Calculating distance
- Calculating the amount of gas to use depending on the efficiency of the car and the number of trips that it must make.
- Computation of CO₂ emissions including a load penalty in the calculation of load-adjusted emissions.
- Estimating the cost of operating business with the existing fuel prices. in Bangladesh

Layer 3: Results and Visualisation

A number of interface elements represent the calculated metrics:

- The results panel demonstrates the cost, CO₂ emissions, fuel use, and distance.
- Bar chart visualisation that compares several scenarios
- Side-by-side comparison of possibilities for sensitivity analysis

This modular design helps it undertake both single case analysis and creating new features, such real-time mapping services or fleet management systems.

3.2 Computational Model Parameters

The simulation tool employs a modular mathematical framework that translates user inputs into quantified environmental and economic outputs. This section details the core computational parameters and formulas that underpin the carbon footprint and cost estimation engine.

3.2.1 Vehicle Efficiency Parameters

Table 1 demonstrates the vehicle efficiency coefficients that have been adjusted for the road conditions, traffic patterns, and vehicle specs that are typical of SME logistics operations in Bangladesh.

Table 1. Vehicle Fuel Efficiency Matrix

Vehicle Type	Efficiency (km/L)	Capacity (kg)
Motorcycle	40	50
Auto-rickshaw (CNG)	25	300
Car	15	500
Van	12	1,000
Pickup Truck	10	900
Small Truck (Mini-truck)	8	2,000
Large Truck	6	5,000

Note. Data adapted from Iyer et al. (2013) and Anthes et al. (2025).

The following Figures (Figure 1- Figure 6) show how the car works in real-life situations, taking into account hazardous roads, hectic city traffic, tropical climate effects, and the usual variety of highway and city driving in Bangladesh.

3.2.2 Fuel Consumption Model

The total fuel consumption will be calculated by distance travelled, fuel consumption of the vehicle, and the frequency of trips. Let:

- The variable ‘d’ represents the one-way delivery distance in kilometers.
- *Evehicle* denotes the vehicle fuel efficiency in kilometres per litre.
- *Ntrips* indicates the number of one-way trips

The total fuel consumed is given by: $F_{total} = (d/E_{vehicle}) \times N_{trips}$

In the existing implementation, the function `calculateFuelConsumption` retrieves *Evehicle* from the `EFFICIENCY_MAP` lookup table. In case the given type of vehicle cannot be identified, it is assumed that the default efficiency equals 12 kilometres per liter (van equivalent). The distance parameter `dd` is set at default to 100 kilometres when no explicit route calculation is done, and this is indicative of an intercity delivery situation with major commercial centres in Bangladesh, such as Dhaka-Chittagong or Dhaka-Khulna.

All numerical results are displayed to two decimal places to ensure the precision of financial numbers and to be understandable to users, this is carried out through the `round2` helper method.

3.2.3 Load Factor Adjustment Model

One of the critical innovations of this model is the factor of dynamic load that takes into consideration the physical reality of the heavier vehicle that consumes a larger amount of fuel because of the greater rolling resistance, aerodynamic drag, and load of its engine. This overcomes a major weakness of the static emission models where the fuel efficiency is assumed to be the same across the board. Let:

- *Wload* represents the actual cargo weight in kilograms
- *Wcapacity* denotes the rated maximum capacity of the vehicle in kilograms

The load factor ‘*LF*’, which adjust fuel consumption and emissions according to vehicle payloads is defined as (Anthes et al., 2025): $LF = 1 + 0.2 \times (W_{load} / W_{capacity})$

This formulation yields the following interpretations:

- Empty vehicle ($W_{load}=0$): $LF=1.0$ (baseline, no penalty)
- Half-loaded vehicle ($W_{load}=0.5 \times W_{capacity}$): $LF=1.1$ (10% emission increase)
- Fully loaded vehicle ($W_{load}=W_{capacity}$): $LF=1.2$ (20% emission increase)

The maximum percentage coefficient of penalty is 20% which is the result of empirical research that was done on commercial vehicle fuel consumption at different load conditions. The `calculateCO2Emissions` function is used to calculate the load utilization ratio and get distinct *LF* as a result. If either *Wload* or *Wcapacity* is not positive or is not a valid number, the system uses $LF=1.0$ to avoid mistakes in the calculations.

The vehicle capacities have been acquired based on the `CAPACITY_MAP` table although the users can overrule the values in the input form to support special vehicles or non-standard payloads.

3.2.4 Carbon Emissions Calculation

The sum of greenhouse gas emissions is obtained by summing the fuel consumption, fuel-specific emission intensity, and the load-dependent factor. Let:

- F_{total} displays the amount of fuel consumed (in litres or kilograms of CNG).
- EF_{fuel} displays the emission factor of the type of fuel that you have selected (kilograms of CO₂ per litre or kilogram).
- *LF* is the load factor as explained in Section 4.2.3.

Using the conventional method for calculating (Anthes et al., 2025), the total amount of carbon dioxide emissions is

$$EC_2 = F_{total} \times EF_{fuel} \times LF$$

Table 2 shows the emission factors to be applied in the model, which are referred to the Intergovernmental panel on climate change (IPCC) Fifth assessment report and to the Bangladesh specific fuel composition report.

Table 2. Fuel Emission Factors (IPCC AR5 Standards)

Fuel Type	Emission Factor (kg CO ₂ /L)	Standard Reference
Petrol	2.31	IPCC 2019
Diesel	2.68	IPCC 2019
Octane	2.39	IPCC 2019
CNG	2.75	IPCC 2019
Electric	0.00	—

Note: Emission factors are taken from IPCC (2019)

The emission factors are well-to-tank carbon intensity that covers refining, extraction upstream and distribution. In the case of electric vehicles, the direct emission factor will be equalized to zero since no combustion will take place; the emission of electricity generation as an indirect emission can be included in the future sensitivity analysis with the aid of the Bangladesh grid emission factors.

The calculateCO2Emissions function implements this calculation and returns *ECO2* rounded to two decimal places.

3.2.5 Operational Cost Estimation

An economic aspect of delivery operations is represented in the fuel cost model that multiplies the total fuel consumption with the unit fuel prices. Let:

- *P_{fuel}* represents the unit price of the selected fuel in Bangladeshi Taka (BDT) per litre or per kilogram.

The total operational fuel cost is given by: $C_{total} = F_{total} \times P_{fuel}$

Table 3 shows the fuel price parameters as incorporated into the model based on official tariffs of Bangladesh Petroleum Corporation (BPC) as at October 2024.

Table 3. Bangladesh Fuel Prices (Q4 2024)

Fuel Type	Price (BDT/L or BDT/kg)	Update Frequency	Source
Petrol	120	Weekly	BPC Official Tariff
Diesel	115	Weekly	BPC Official Tariff
Octane	130	Weekly	BPC Official Tariff
CNG	85	Monthly	BPC Official Tariff
Electric	8 (per kWh)	Monthly	BPDB Grid Rate

Note: Fuel prices are taken from BPC and BPDB official tariffs (BPC, 2024; BPDB, 2024).

The prices are stored in the FUEL_PRICES look-up table and it can be updated when the market conditions vary. This calculation is performed in the calculateFuelCost function which yields the (rounded to two decimal places) value of total and is consistent with Bangladesh banking and accounting standards.

3.3 Input Variables and Operational Parameters

The simulation model assumes a short list of parameters that are specified by the user to the runSimulation function. To be robust, all the inputs are verified and converted to numbers by a safe numeric parser (toNumber) that does not allow any invalid input to enter and result in a calculation error.

Table 4 represents the entire list of input variables, their involvement in the calculation process, and their common values in the context of Bangladesh SME logistics.

Table 4. Model Input Variables and Specifications

Input Variable	Internal Role	Data Type	Source	Default/Fallback
Start Location	Route context label	Categorical	User selection	N/A
Destination	Route context label	Categorical	User selection	N/A
Vehicle Type	Index for efficiency and capacity lookup	Categorical	User selection	Van (12 km/L)
Fuel Type	Index for emission factor and price lookup	Categorical	User selection	Diesel
Number of Trips	Trip frequency multiplier	Integer	User input	0
Load Amount	Cargo weight in kilograms	Continuous	User input	0 kg
Vehicle Capacity	Payload capacity override	Continuous	User input or default	From CAPACITY_MAP
Distance	Route distance in kilometres	Continuous	Default (100 km) or user-provided	100 km

The prototype currently being discussed uses the origin and destination as labels used by a user in the context but not to calculate the actual distance. A distance of default of 100 kilometres is used, which is a representative medium-haul intercity delivery characteristic of the operations of Bangladesh SME. Real-time calculating of the distance can be added in future versions with the help of mapping APIs, e.g. Google Maps Distance Matrix or OpenStreetMap routing services.

3.4 Scenario Comparison and Sensitivity Analysis

The simulation tool allows two scenarios of user defined delivery to be compared side-by-side to allow systematic sensitivity analysis of the multiple operational dimensions. Users can compare:

- Alternatives routes: Alternative origin-destination pairs of the same delivery.
- Vehicle options: the vehicle options are alternative vehicles of the same route and carrying the same payload.
- Alternative fuel: There are other types of fuel with the same parameters of operation.
- Load conditions: Impact of partial and full capacity loading.
- Trip consolidation: Effect of combining many trips into few and full loads.

In every comparison, the system computes: Absolute and percentage differences in:

- Distance traveled (kilometres)
- Fuel consumed (litres)
- CO₂ emissions (kilograms)

- Operational cost (BDT)

This feature helps SMEs to measure the environmental and economic value of changes in operation, which will facilitate the use of evidence-based decisions and gradual streamlining of logistics processes in accordance with them.

3.5 Summary of Methodological Approach

The methodology outlined here is a combination of:

- A transparent, tabular application of vehicle efficiencies, emission factor, fuel prices and capacities within Bangladesh SME logistics situations.
- An effective mathematical model that involves four interrelated equations on fuel consumption, load-adjusted emissions, cost estimation to operate and a financial analysis.
- Flexible input architecture to provide both abstract scenario analysis and future interconnection with real time distance calculation and fleet management systems.
- The ability to compare scenarios which allows systematic sensitivity analysis and quantification of potential improvement throughout the operating parameters.

This package also puts the tool in a position to fulfill the needs of several stakeholders: (i) as an educational resource in learning about logistics emissions, (ii) as a decision support tool that can be used by small delivery operators, (iii) as a policy consistent tool in the ability to measure and incentivize the uptake of sustainable logistics practices by SMEs in Bangladesh in accordance with Sustainable Development Goals 12 (Responsible Consumption and Production) and goals 13 (Climate Action).

4. Results and Discussion

This section demonstrates the utilization of the web-based simulation tool and its outcomes through case studies which are relevant to the context of Bangladeshi SMEs. The findings show that the tool is capable of assessing the operational expenses and carbon footprints of different logistical scenarios. Additionally, we conduct a sensitivity analysis to identify optimal strategies for fuel utilization, route planning, and vehicle selection, providing a mathematical basis for sustainable decision-making.

4.1 System Implementation

The simulation tool was created effectively and achieved a fully functioning web-based application, which incorporated the Formation vendor of React.js frontend, the JavaScript calculator engine, and interactive visualization. The entire system includes React components, a modular calculation module with export functions, and library utility support for PDF.

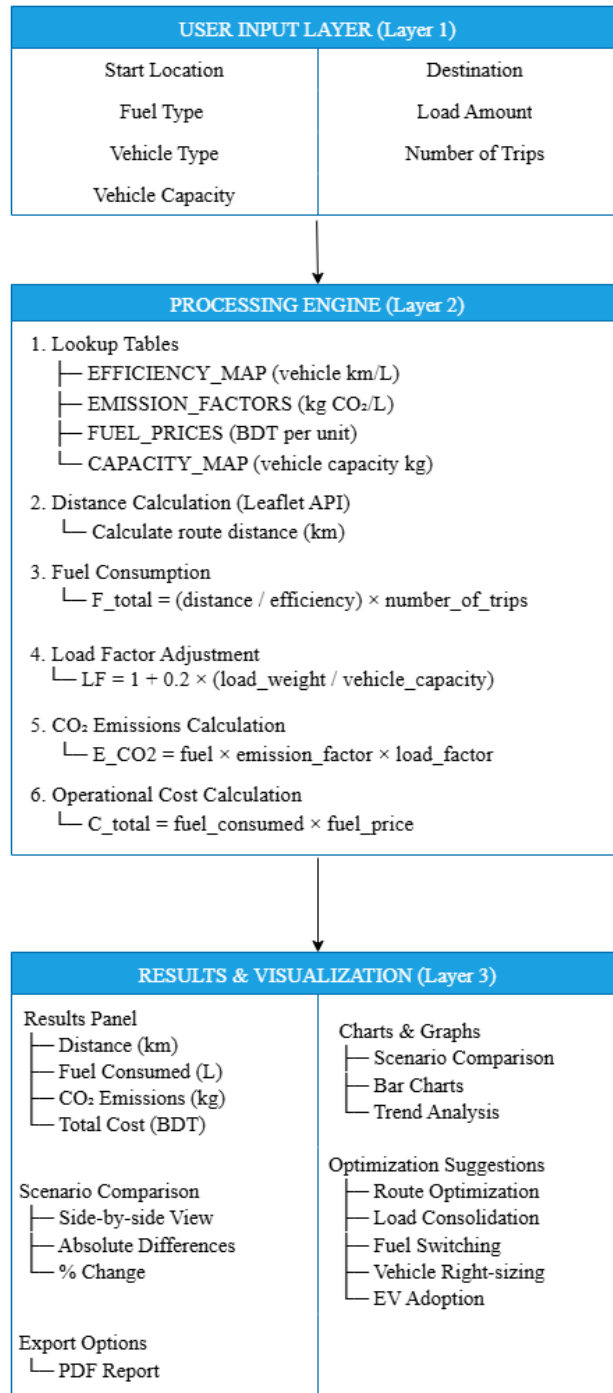


Figure 1. Schematic diagram of the simulation tool showing the interaction between the User Input Layer, the core Processing Engine, and the Visualization interface.

The architecture diagram shows the data flow coming to the calculation engine from the user input and to the results visualization. The modular structure allows testing every calculation systems individually and connecting to external services in the future, e.g., mapping APIs or vehicle telematics systems.

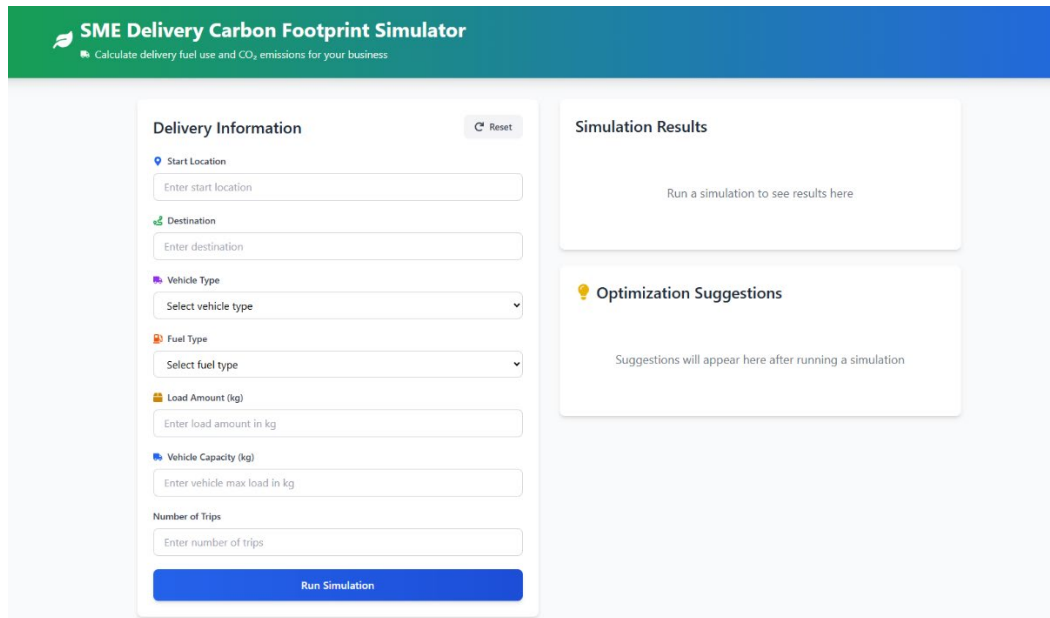


Figure 2. Overview of the application dashboard and user interface design.

The design of the user interface allows displaying all the necessary information on one scrollable page, which reduces the cognitive burden of the use of the tool by non-technical SME operators. The use of color-coded elements, intuitive form fields, and explicit labeling makes it accessible to users with a low digital literacy level.

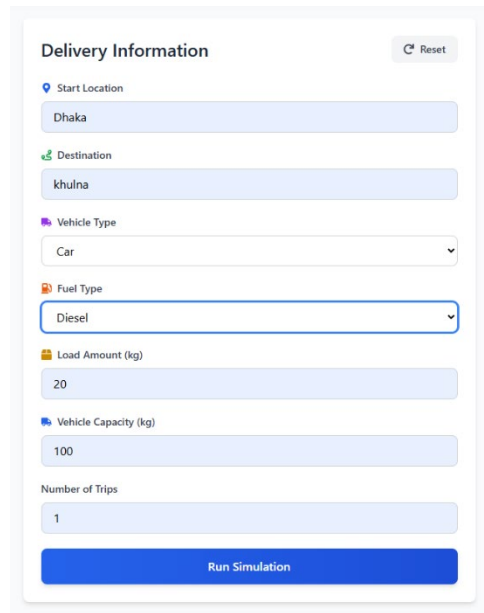


Figure 3. Detail of the parameter input form allowing users to specify route origin, vehicle characteristics, fuel type, and load details for a simulation run.

The input form realizes typical web form controls with built-in validation. The use of dropdown menus would restrict the entries in the vehicle and fuel options to predefined ones, avoiding invalid entries. The numeric fields accept continuous values that are realistic for the operations of SMEs in Bangladesh.

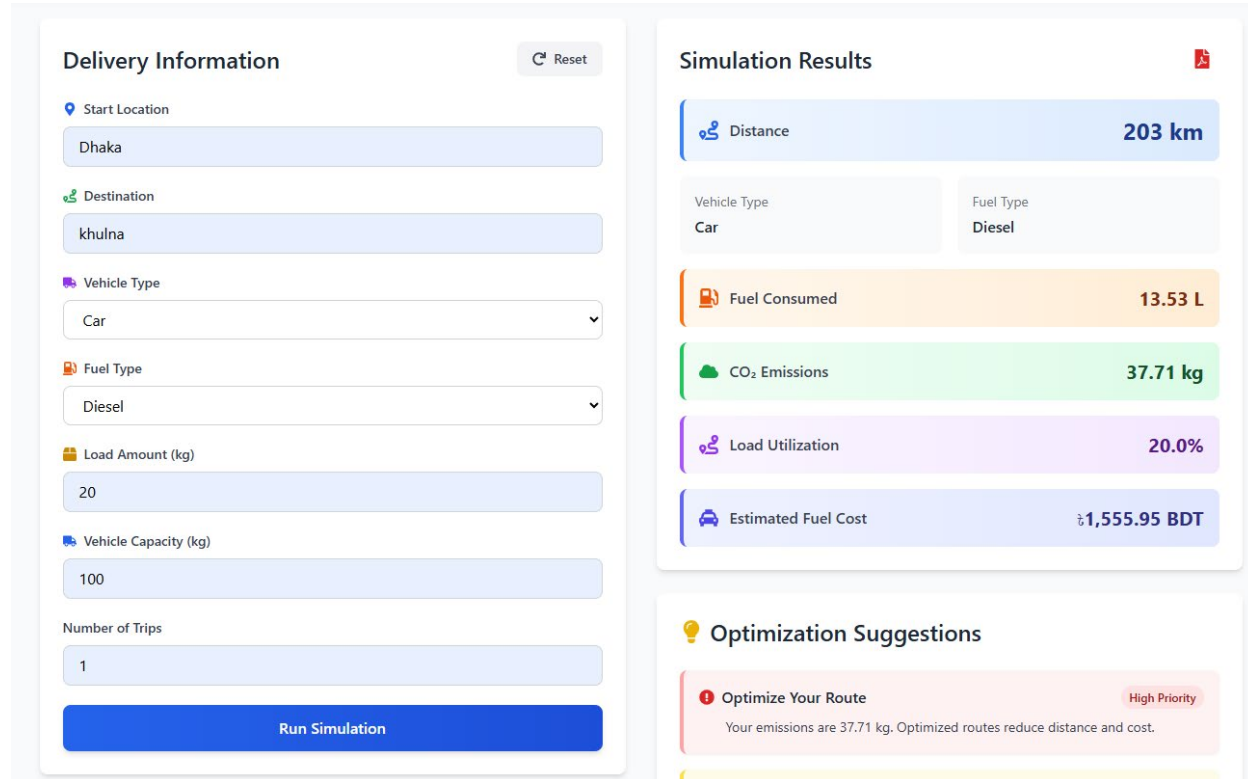


Figure 4. Simulation results panel displaying key metrics including fuel consumption, CO₂ emissions, load utilization, and operational cost, along with optimization suggestions for emission reduction.

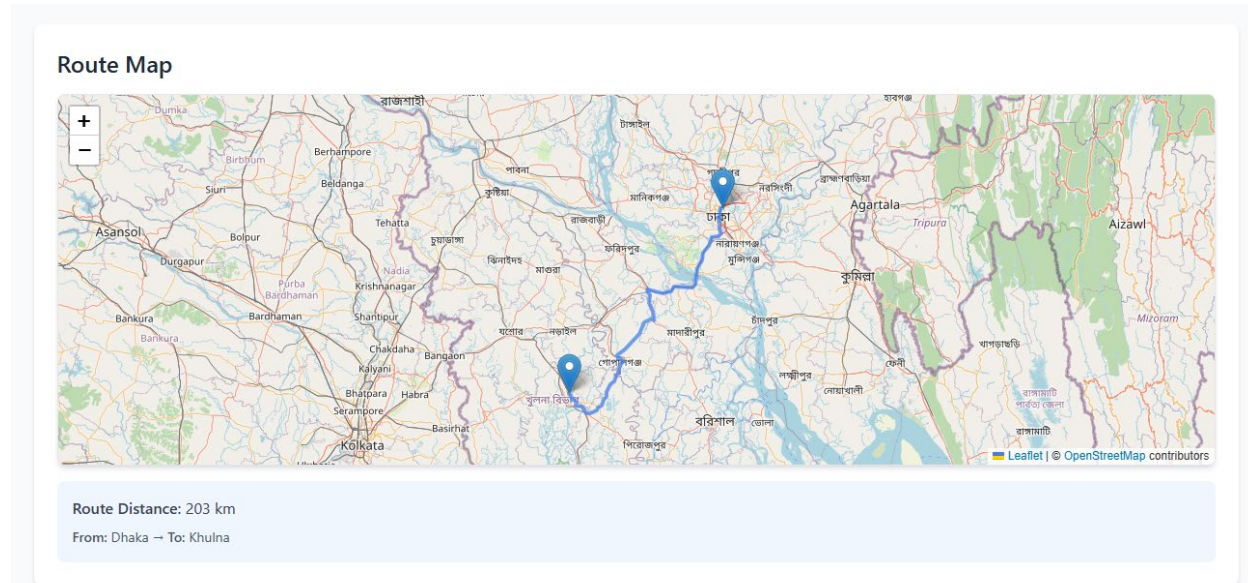


Figure 5. Route map displaying the calculated delivery distance between origin (Dhaka) and destination (Khulna).

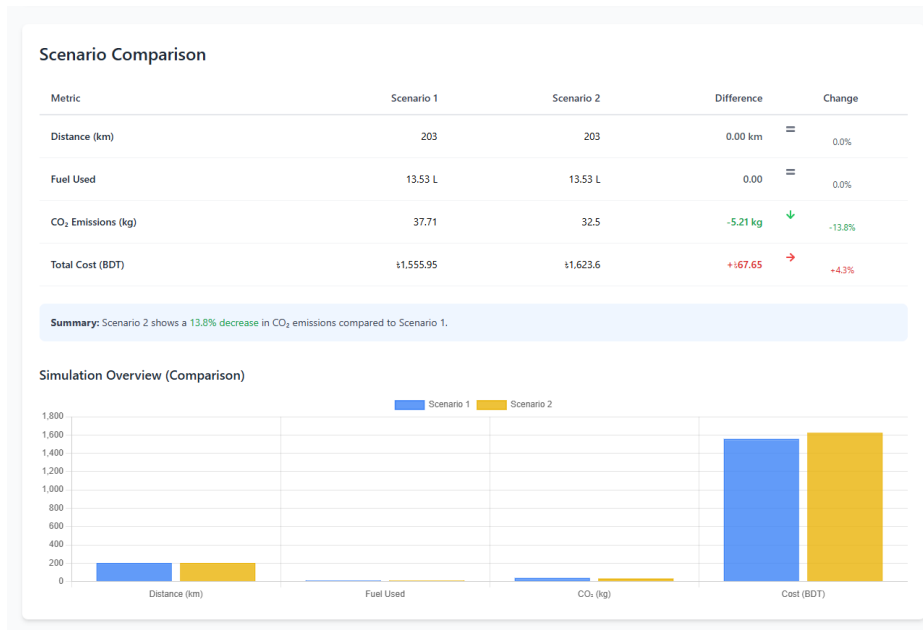


Figure 6. Comparative analysis interface showing quantitative metrics and visual charts for scenario sensitivity analysis.

The interface of the results has three main visuals which are used to aid in the process of decision-making. The metrics (Fig.4) have been calculated and expressed in the results panel in the form of individual cards with appropriate units and the figures have been rounded to two decimal points, which is vital in financial analysis. The route map (Fig.5) confirms the delivery route and gives the actual distance. Lastly, the tool of scenario comparison (Fig.6) provides a side analysis both in a tabular format and bar chart format in which the user can easily compare the trade-offs of alternative ways to deliver.

4.2 Case Study Analysis

The effectiveness of the tool was proved by the controlled comparison of the four types of vehicles, with the help of such conventional parameters as the distance of 203 km (the route of Dhaka and Khulna) and a load of 50 kg and one trip of delivery. This distinguishes vehicle efficiency from capacity utilization as the two primary variables (Table 5).

Table 5. Comparative Analysis of Vehicle Efficiency

Scenario	Vehicle	Fuel Type	Max Capacity (kg)	Fuel (L)	CO ₂ (kg)	Cost (BDT)
Case A	Motorcycle	Petrol	100	5.08	12.91	609.60
Case B	Car	CNG	300	13.53	38.45	1,150.05
Case C	Van	Diesel	800	16.92	45.91	1,945.80
Case D	Small Truck	Diesel	2000	25.38	68.36	2,918.70

(Parameters: Distance = 203 km | Carried Load = 50 kg | Trips = 1)

The uniform research demonstrates significant weaknesses in the choice of vehicles. The most efficient with the 50 kg cargo weight is the Motorcycle (Case A), which uses 5.08 liters of fuel, produces overall CO₂ emissions of 12.91 kg/kg at 609.60 BDT. On the contrary, Small Truck (Case D), which has the low-capacity utilization of 2.5%, burns 4.99 times more fuel, produces 68.36 kg of CO₂ (a 430% increase), and has the cost of 2,918.70 BDT (a 378% increase). The intermediate versions of Car (Case B) and Van (Case C) perform worse, by 2-4 times, as compared to the right-sized motorcycle. These data indicate that the major cause of high pollution and operation costs in the

logistics of SMEs is the poor use of vehicles. Section 4.3 of the sensitivity analysis examines various viable intervention strategies which include route optimization, load consolidation, and vehicle right-sizing in order to help SMEs reduce their environmental impact and cost.

4.3 Sensitivity Analysis and Optimization Strategies

A systematic sensitivity analysis was performed, which determined the best leverages to use in decarbonization and the reduction of costs. The analysis investigated four major intervention strategies of route optimization, load splitting/consolidation, fuel switching and right-sizing of the vehicle.

4.3.1 Route Optimization

Route optimization employs distance minimization through the use of superior routing software or consolidation centers. The examination of Case C (Van with a 50 kg load) as the baseline shows a direct linear correlation between route distance, emissions, and costs (Table 6).

Table 6. Impact of Distance Reduction (Baseline: Case C - Van)

Distance Scenario	Distance (km)	Fuel (L)	CO ₂ (kg)	Cost (BDT)	Reduction %
Baseline	203	16.92	45.91	1,945.80	—
10% Reduction	182.7	15.23	41.32	1,751.22	10.0%
20% Reduction	162.4	13.53	36.73	1,556.95	20.0%
30% Reduction	142.1	11.84	32.14	1,362.48	30.0%

A 20 percent decrease (from 203 km to 162.4 km) leads to corresponding 20 percent savings in fuel consumption, CO₂ emissions, and operational costs. This leads to in a savings of around 388.85 BDT and 9.18 kg of CO₂ every delivery trip for a SME that conducts 20 deliveries monthly. A 30% decrease in distance will result in even more savings, resulting to a cost of 1,362.48 BDT and an emission of 32.14 kg CO₂ each trip. Route optimization is a cost-effective intervention that may be applied promptly and yields significant consequences.

4.3.2 Load Strategy: Single Heavy Trip vs. Split Light Trips

A rigorous comparison analysis was conducted on the conventional notion that larger vehicles are invariably more efficient. We employed three ways within the fleet to evaluate the transportation of a 1,000 kg load over a distance of 100 km (Table 7).

Table 7. Comparative Analysis of Load Strategies (1,000 kg Load)

Strategy	Vehicle Configuration	Distance	Fuel Efficiency	Total CO ₂ (kg)	Total Cost (BDT)
Option A (Single Heavy Trip)	1 × Large Truck	100 km	3.5 km/L	79.62	3,286
Option B (Split Standard)	2 × Pickups	100 km	10.0 km/L	59.49	2,300
Option C (Split Efficient)	2 × Vans	100 km	12.0 km/L	49.12	1,916
Impact (A vs C)	—	—	—	-38.3%	-41.7%

Findings:

- Option A (Large Truck): The truck has the highest emissions (79.62 kg); though it makes a single trip, the fuel consumption of the truck (3.5 km/L) is not good, and the capacity is not fully utilized (20%).
- Option B (Pickups): The use of two pickups can increase efficiency by a great margin, as the emissions drop to 59.49 kg (-25.3%), which proves that the size of a vehicle is more important than the number of trips.
- Option C (Vans): The best course of action is to make use of the most fuel-efficient cars. Two trips in the modern vans (12 km/L) generate 49.12 kg CO₂, a 38.3% decrease in emissions, and a 41.7% decrease in the price in comparison with the single heavy truck.

This discussion proves that in the case of mid-sized loads (1,000 kg), right-sizing the vehicle fleet, including making more trips, is much more sustainable and cost-efficient than running heavy-duty trucks with excess capacity.

4.3.3 Vehicle Right-Sizing

Comparing vehicle classes for a fixed 500 kg load revealed substantial inefficiencies in using oversized vehicles (Table 8).

Table 8. Vehicle Class Comparison (500 kg Load)

Vehicle	Load Utilization	CO ₂ Emissions (kg)	Cost (BDT)
Large Truck	10%	79.71	4,059.60
Small Truck	25%	61.56	3,045.60
Van	62.5%	43.97	2,030.40

The findings reveal that there is a direct relationship between the use of vehicles and their efficiency. The Large Truck, which has a utilization rate of 10%, emits the highest amount of CO₂ at 79.71 kg and incurs the highest cost at 4,059.60 BDT. Using the van (62.5% utilization), the best performance is at 43.97 kg CO₂ and 2,030.40 BDT, a 44.8 percent reduction in emissions and a 50 percent reduction in cost as compared to the large truck.

Right-sizing of vehicles, i.e., alignment of vehicle size to the size of the payload, is among the most suitable solutions to enable SMEs to reduce carbon footprint and logistics cost at the same time. Replacing the large truck with a well-sized van also reduces emissions and the costs associated with this delivery profile by half.

4.3.4 Fuel Switching

The analysis evaluated the environmental and economic impact of switching fuel types for a standardized Van operating on a 203 km route with a 100 kg load (Table 9).

Table 9. Fuel Type Sensitivity Analysis (Vehicle: Van)

Fuel Switch	CO ₂ Change	Cost Change	Analysis
Petrol → Diesel	+16.0%	-4.2%	Slightly cheaper but more polluting.
Diesel → CNG	+2.6%	-26.1%	Significant cost savings but no environmental benefit.
Diesel → Electric	-100%	-90.6%	Zero emissions and 90% cost reduction—optimal solution.

(Direct tailpipe emissions only)

Analysis:

The results indicate the existence of three distinct trade-offs:

- Petrol versus Diesel: Diesel reduces expenses little (-4.2) but increases emissions by over 16 percent.

- Diesel versus CNG: CNG offers substantial cost reductions (-26.1), although does not confer environmental benefits (+2.6% rise in emissions).
- Diesel versus Electric: Electrification eliminates all pollution and reduces costs by 90%. For the SMEs, this will result in rapid returns solely in terms of operational savings.

The only fuel strategy that can optimize profitability and environmental performance, hence offering the most effective option for the long-term sustainable logistics of SMEs, is fleet electrification.

4.4 Integrated Cost-Benefit Analysis

The cumulative impact of these actions was modeled for a typical mid-sized SME logistics company (20 trips per month, averaging 100 km) (Table 10).

Table 10. Cumulative Impact of Optimization Strategies

Intervention Level	Strategy Combination	Monthly CO ₂ Reduction (kg)	Monthly Cost Savings (BDT)
Basic	Route Optimization Only	89	3,833
Intermediate	+ Vehicle Right-Sizing	134	5,750
Advanced	+ Load Consolidation	200	12,000
Strategic	+ Fleet Electrification	445	14,000

Economic and Environmental Projection:

A hybrid approach work plan consisting of vehicle right-sizing and route optimization can decrease the annual carbon footprint of an SME by circa 1.6 tons of CO₂ and save the company approximately 69,000 BDT each year. This kind of expenditure is a significant financial stimulus and it amounts to approximately 8-10 percent of the average logistical operational expenses of the microenterprises.

4.5 Discussion

The findings indicate that we can realize the decarbonization of SME logistics in Bangladesh on a large scale without prohibitive capital investment. Route optimization and vehicle right-sizing are the easiest interventions to implement, as they require only informational modifications rather than technological improvements. The discussion reveals, in particular, that:

- Information asymmetry is a barrier: The primary reason it is impossible to reduce high emissions is the lack of adequate planning information, which stems from confusion regarding vehicle sizes and their loading capacities.
- Economic Alignment: In the majority of the interventions (except switching with petrol/octane), the aim of environmental objectives is in line with the economic incentives, which implies that cost minimization can be employed as a framing of sustainability.
- Split-Load Viability: Splitting the loads into smaller, more efficient vehicles can be carbon-negative when paired with route optimization, which provides flexibility to SMEs who cannot move bulk shipments of a large size.

These results confirm the usefulness of the developed web simulation tool as a decision-support tool that can be used to uncover these non-intuitive optimization opportunities in the minds of SME operators.

5. Conclusion

This research project generated a web-based carbon footprint evaluation simulation software to support logistics planning based on data to the purposes of the Small and Medium Enterprises (SMEs) in Bangladesh. The outcomes

of the simulation have shown that a holistic optimization strategy which includes route optimization as well as vehicle right-sizing has the potential to reduce the carbon emissions of an SME by 1.6 tones/year and enable them to make a saving of about 69,000 BDT on operating costs.

The underlying principle of the experiment was a significant challenge to the traditional principles of logistics as it demonstrated the fact that the division of cargoes into more efficient but smaller trucks led to the decrease in emissions by 38.3 percent as compared to poorly utilized lorries. The framework will add to the gap between complex emission models and the daily business decisions of Bangladeshi SMEs by providing a viable route through which these trade-offs can be influenced positively by the user-friendly tool that enables monitoring of these trade-offs.

6. Future Work

The existing model, whereby Leaflet is employed to make simple distance estimations, will be subject to various improvements to make it more accurate and useful.

- Combination of Business APIs. Future versions will focus on switching to commercial routing APIs (e.g. Google Maps Distance Matrix) rather than using simple calculations based on coordinates. These algorithms will consider the real world factors like congestion at an average time and road surface conditions and accurate turn by turn navigation which will be vital in the overpopulated urban environment of Bangladesh.
- Machine Learning in Demand Forecasting: Given historical data regarding the number of users, machine learning may be utilized to forecast peaks in deliveries. This would enable the system to anticipatively advise the milk run merge option to maximize fleet employment and then depart.
- Expansion of Multimodal Logistics: The current framework primarily concentrates on road transportation. The subsequent step of growth will encompass the inland water delivery and provide the comprehensive analysis of emissions in the cases of cross-border supply chains
- Lifecycle Analysis (LCA): To further represent an inclusive environmental analysis, the indirect emissions to be considered in future will include the carbon intensity of grid electricity to energize electric vehicles and the embodied carbon of vehicle manufacture.

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Farah Tabussum (Dhaka, Bangladesh) is an undergraduate student of Computer Science and Engineering (CSE) at BRAC University. Her academic interests include computer science research, web development, and UI/UX design. In addition to her technical work, she is also engaged in writing and enjoys reading, which fosters her creativity and critical thinking.