

Fleet Electrification for Public Transit: An Economic Assessment of Intercity Bus Operations in Kutch.

A

Synopsis submitted

to



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Abstract

The extensive use of fossil fuels in transit buses has led to both environmental problems and fuel scarcity. Renewable energy has emerged as a potential solution to mitigate these issues. Many countries worldwide have already adopted renewable energy to address these challenges. Similarly, the Indian government has initiated e-vehicle adoption in various sectors through subsidies to reduce dependence on conventional fuels. This research investigates the key areas: Fuel consumption dependency and air quality impact assessment for diesel-operated public buses fleet (GSRTC) with exploring the fleet electrification possibilities i.e., replacing with EV-Buses. This research employs a three-stage energy modeling methodology: Route Energy Planning (REP), Charging Infrastructure Planning (CIP), and Total Cost of Ownership (TCO) and relevant analysis. The study explores the potential for fleet electrification for Kutch division of GSRTC, aiming to replace existing diesel-powered internal combustion engines (ICEs) buses with environmentally friendly EV-Buses. Out of 157 buses operating over 82,196 km route length in Kutch, 30% (48 buses) were targeted to replace in first stage. Using a 25% minimum SOC (state of charge) threshold, 119 ICE-buses were shortlisted, and after optimizing charging schedules, 61 were finalized as priority. An analysis of annual costs, for both ICE diesel and EV-buses, conducted, considering bus capitalization, battery capitalization, charging infrastructure, and annual operation costs. The findings revealed that the TCO for an EV-bus is significantly lower than that of a diesel bus (44.46 Rs/km vs. 50.99 Rs/km). This study evaluates the viability of implementing electric mobility for the Gujarat State Road Transport Corporation (GSRTC) in Kutch District, India, to promote sustainable transportation and reduce emissions. The methodology, involved to assess Net Present Value (NPV) and Internal Rate of Return (IRR) using a functional unit of one bus traveling 220 km daily was developed. The bus station and route were digitized in GIS format, enabling precise mapping and spatial analysis.

1. A Brief description on the state of the art of the research topic

India's "Shoonya -Zero Campaign" pursues the ambitious objective of achieving net zero emissions by 2070. [1-3]. The Shoonya campaign promotes zero-emission vehicles to reduce transport pollution, especially in urban areas. Supported by initiatives like, “The National Electric Mobility Mission Plan 2020” (NEMMP 2020), it highlights sustainable transport as essential for greener, cleaner cities [1-3]. India’s NEMMP 2020 aims to reduce oil dependence by promoting electric and hybrid vehicles. Under this, the FAME (Faster Adoption and Manufacturing of Electric Vehicles) India scheme supports technology development, public awareness, pilot projects, and charging infrastructure [4]. The reference article assesses energy usage models for the Asian region [5]. The model suggests that in developing countries, reducing transport-related carbon emissions requires not just lowering carbon intensity but also decoupling energy use from economic growth [6]. The paper proposes a novel framework to assess energy security and examines its interactions with climate change policies. [7]. A Transport Energy Consumption (TEC) model assesses the design, operation, and lifecycle of Electric Buses in Jilin Province of China; highlighting that widespread EV adoption is essential for cleaner roads and achieving carbon neutrality [8]. The study introduces an advanced fleet management system for electric vehicles, offering real-time services to enhance monitoring and optimize EV fleet operations [9]. The study, based on data from 60 routes and five EV models, offers reliable insights into transport patterns in Germany, [10]. The study introduced EV charging stations, detailing charging duration, non-linear charging profiles, and service time and frequency to optimize electric vehicle operations [11].

Ref.	Author(s)	Journal / Volume / Pages / Year / Publisher	Objectives / Methodology	Key Outcomes	Relevance to Present Research
[12]	Zhou W., Wang L.	J. Adv. Transp., 2019, pp. 1–16.	Developed a dynamic route-planning model for EVs under uncertain travel times using adaptive	Enhanced route efficiency, reduced energy use, and	Demonstrates optimization models for real-time, energy-

			control and energy-efficient algorithms.	improved travel-time reliability.	efficient EV routing.
[13]	Perger T., Auer H.	Energy Efficiency, 2020, 13(8):1705–1726.	Designed an energy-efficient route-planning approach considering topography and battery lifetime.	Found that elevation changes strongly affect EV energy consumption and route selection.	Highlights terrain's impact on EV routing and energy modeling.
[14]	Khandekar A., Rajagopal D., et.al.	Energy Technologies Area, 2018.	Evaluated the feasibility of full electrification of India's city bus fleets.	Electrification requires minimal power share and enhances cost/environmental efficiency with renewables.	Supports large-scale EV adoption policies.
[15]	Deb S., Tammi K., et.al.	IEEE Access, 2019, 7:100270–100282.	Proposed an optimization model for EV charging station placement in Guwahati, considering network topology, economy, and grid load.	Identified optimal station locations enhancing convenience and grid stability.	Provides an EV infrastructure planning framework for Indian cities.
[16]	Mathiesen B.V., Lund H., et.al.	Applied Energy, 2011, 88(2):488–501.	Modeled 100% renewable energy systems integrating transport and power sectors.	Demonstrated economic growth potential alongside deep decarbonization.	Lays foundation for integrating transport electrification into renewable systems.
[17]	Singh N., Mishra T., et.al.	Preprint, 2021.	Built a road transport emissions inventory for India (2020) and evaluated policy impacts.	Provided framework for post-facto policy assessment of emission control.	Supports national-scale emissions benchmarking.
[18]	Sheth A., Sarkar D.	Transportation in Developing Economies, 2021, 7(1).	Conducted social benefit–cost analysis for electric bus transit in Ahmedabad.	Found high social and environmental benefits vs. conventional buses.	Demonstrates socioeconomic viability of e-bus projects.
[19]	Napitupulu B., Ismiyati I., et.al.	MATEC Web of Conferences, 195, 04021 (2018).	Simulated effects of public transport design changes on urban air pollution.	Found emission reductions of NOx, SO ₂ , PM, Pb, CO >48%.	Supports modal shift toward public transport to cut emissions.
[20]	Ferrer A.L.C., Thomé A.M.T.	Sustainability, 2023, 15(11):8475.	Conducted meta-analysis on carbon emissions frameworks in transportation.	Urged rapid adaptation for climate resilience and mitigation.	Provides a holistic sustainability framework for transport planning.
[21]	Jing Q.-L., Liu H.-Z., et.al.	Sustainability, 2022, 14(10):6248.	Studied public transport's impact on carbon emissions from an energy-consumption viewpoint.	Found that optimized public transport substantially cuts CO ₂ emissions.	Reinforces need for energy-efficient urban transit systems.
[22]	Brohi S.N., Pillai T.R., et.al.	IOP Conf. Ser.: Earth Environ. Sci., 2018, 167:012015.	Assessed smart city transport systems and air pollution links in Malaysia.	Found strong correlation between vehicle activity and urban air pollutants.	Highlights need for smart traffic management and emission monitoring.

[23]	Dey S., Mehta N.S.	Resources, Environment and Sustainability, 2020, 2:100006.	Reviewed catalytic technologies for automobile pollution control.	Identified effective catalytic converters and fuel additives.	Contributes to cleaner combustion strategies during EV transition.
[24]	Singh N., Mishra T., et.al.	Preprint, 2021.	Developed emissions inventory for India's 2020 road transport sector.	Quantified pollutant loads; proposed control policy evaluation framework.	Key dataset for comparing conventional vs. EV fleet emissions.
[25]	Manzolli J.A., Trovão J.P., et.al.	Renew. Sustain. Energy Rev., 2022, 159:112211.	Reviewed electric bus research trends, methods, and topics.	Identified key areas: fleet optimization, battery management, sustainability.	Defines future research trajectory for electric buses.
[26]	Fabianová J., Janeckova J.	Open Engineering, 2021, 11(1):907– 914.	Conducted NPV analysis of investment in electric buses for a public transport company.	Showed profitability under financial support due to lower operation costs.	Quantifies economic benefits of e-bus investment.
[27]	Fabianová J., Janeckova J.	Adv. Sci. Technol. Res. J., 2022, 16(4):96–105.	Compared economic performance of electric vs. CNG buses.	Electric buses had higher costs but better long-term sustainability.	Informs decision- making for fleet renewal strategies.
[28]	Johnson C., Nobler E., et.al.	National Renewable Energy Laboratory, 2020.	Performed financial analysis of battery-electric transit buses.	Found BEBs cost- effective over lifetime despite higher upfront costs.	Supports financial viability of BEBs in public transport.
[29]	Nordelöf A., Romare M., et.al.	Transp. Res. Part D: Transp. Environ., 2019, 75:211– 222.	Conducted life cycle assessment of buses powered by electricity, HVO, or diesel.	Electrified buses had lowest lifecycle emissions when powered by renewables.	Supports low- carbon technology selection in bus fleets.
[30]	Holland S.P., Mansur E.T., et.al.	Energy Policy, 2021, 148:111921.	Analyzed environmental benefits of urban bus electrification.	Found significant emission reductions and urban air-quality gains.	Demonstrates large- scale environmental benefits of e-bus adoption.
[31]	Matthews B.H.S., et.al.	J. Infrastructure Systems, 2001, 7(1):13– 17.	Quantified external costs of transport-related air emissions.	Highlighted hidden social and health costs of transport pollution.	Provides foundational evidence for cost– benefit analysis in transport policy.

Several of the Government's flagship programs—such as *Swachh Bharat*, *Make in India*, *Skill India*, and *Digital India*—are closely aligned with the Sustainable Development Goals (SDGs). Our study focuses on these goals [32]. SDG 8 plays a central role in India's SDG research ecosystem. Bridging

regional disparities in performance, embedding SDGs within state and national policies with clear timelines, and strengthening international collaboration are essential for accelerating progress, particularly toward SDGs 7 and 13 [33].

2. Motivation and Definition of the Problem

Clean energy development: to lower carbon footprint: To reduce the environmental impact of transportation, clean energy solutions are essential. Electric vehicles powered by renewable energy can cut emissions significantly, while investment in public transport like electric buses and rail, reduces car usage. Smart traffic systems, urban planning for walking and cycling, and innovations like sustainable aviation fuels and hydrogen transport further support low-emission mobility. These efforts collectively promote sustainable transportation and minimize dependence on fossil fuels.

Increasing rate of population: Rapid population growth is driving increased demand in the transportation sector, leading higher vehicle emissions, air and noise pollution, and traffic congestion. This growth contributes to climate change, health risks, and productivity loss. Expanding transport infrastructure often causes habitat loss and deepens fossil fuel dependence, while safety concerns and unequal access worsen social and economic disparities.

India's future trend: market competitiveness: India's electric vehicle (EV) sector is rapidly growing, driven by government support, rising consumer demand, and increased investment from major automakers and startups. Incentives and expanding charging infrastructure are accelerating the shift toward sustainable mobility, reducing fossil fuel dependence, and supporting environmental goals.

Reducing energy dependence: By 2050, global dependence on fossil fuels is expected to drop from 80% to 50%, driven by the growing adoption of renewable energy [38]. This shift is fueled by technological advances, lower renewable energy costs, environmental concerns, supportive policies, and increasing public demand for sustainability.

3. Objectives and scope of the work:

The transportation segment globally plays a meaningful role in worsening air quality and negatively impacting living beings' health. Some key factors to be taken care have been identified: conserving energy, enhancing energy security by reducing dependence on conventional fuels, minimizing the carbon footprint by curtailing greenhouse gas emissions, and enhancing air quality through the reduction of other pollutants. To address these issues, the research has been framed to work on Gujarat State Road Transport Corporation Regional Bus Transit operation in Kutch Region. The below objectives were identified:

1. To assess existing bus transit fleet's fuel consumption dependency and air quality impact assessment of diesel operated buses of GSRTC, Kutch,
2. To explore stage wise Fleet Electrification feasibility,
3. To evaluate the optimum probability of replacing existing fuel to environment friendly sustainable energy source.
4. To analyze environmental and economic benefit with respect to proposed fleet electrification.

4. Original contribution:

The research has been carried out with an aim of planning Fleet Electrification for Public Transit i.e., replacing traditional ICE diesel buses with electric vehicles (EVs). In the present research the entire and collection of data in which problems related to dependency of transport study is divided into four

major steps. The first stage involves identification of problems sector on gasoline-based energy and its

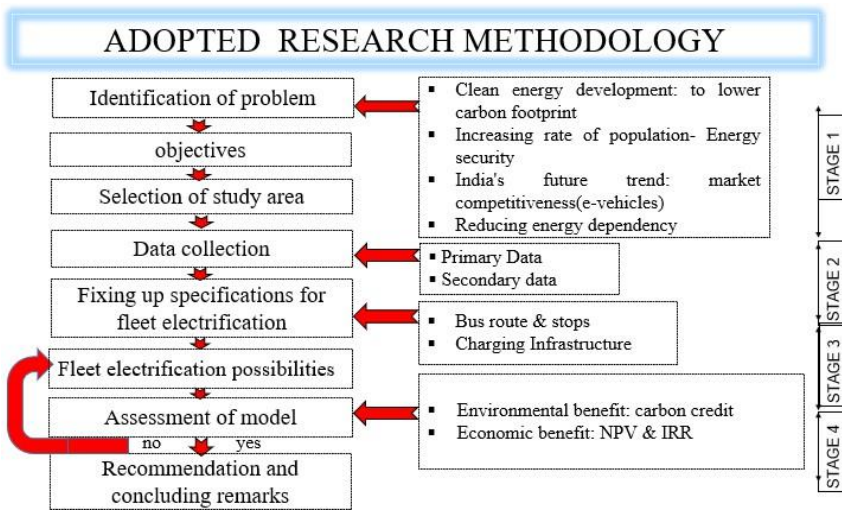


Fig no 1: ADOPTED RESEARCH METHODOLOGY

consequences were identified and objectives for the present study were defined. In the second stage, keeping in mind the necessity of reducing energy dependence and objectives of exploring fleet electrification possibilities,

data was collected from a selected study area, GSRTC Kutch Region, and based on the recommendations extracted from literature, the standard specifications were fixed for charging infrastructure, operational efficiency, and cost optimization. During third stage, collected data was further analyzed and modeled to access fleet electrification possibilities considering various optimization parameters. In stage four the model output was assessed based on environmental benefit: carbon credit and economic benefit: Net present value (NPV) & Internal rate of return (IRR) with its potential for implementation and final recommendations were given.

5. Methodology of Research, Results / Comparisons

Materials and Methods

This study aims to integrate electric mobility with bus transportation systems in Kutch region of Gujarat, India. To conduct a comparative analysis and calculate life cycle costs, the study considers 157 buses serviceable unit of a single bus operating 220 km for 10 years of useful life.

5.1 Study Area Delineation and Data Collection

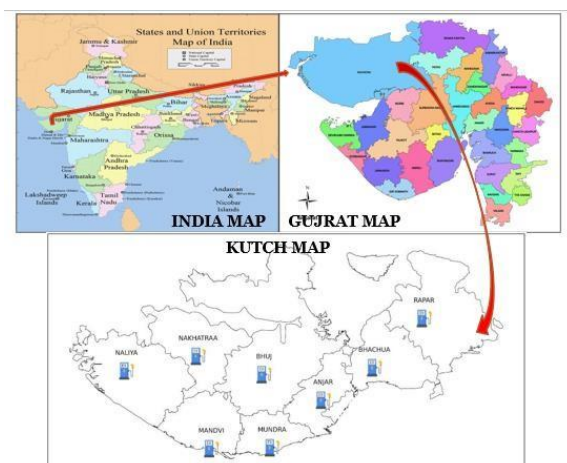


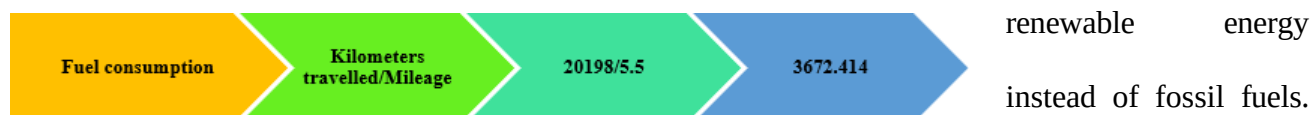
Fig no 2: map of India, Gujarat, and Kutch

Kutch is the largest district in Gujarat, India, covering an area of 45,674 km². The Kutch-Bhuj GSRTC Division is divided into eight main bus depots, including Bhuj, Bhachau, Mandvi, Rapar, Mundra, Naliya, Anjar, and Nakhatrana. There are total of 203 major routes in the Kutch-Bhuj. Data on different types of buses operated by GSRTC in the Kutch district

including bus type, distance traveled in kilometers, departure times, and arrival times, cost of fuel(diesel) were obtained from the Bhuj divisional office.

Objective 1: To assess existing transportation fuel consumption dependency and Air quality impact assessment of diesel operated public bus (GSRTC).

Electric vehicles (EVs) reduce diesel consumption because they use electricity produced from



This not only reduces fuel use, but also helps lower emissions and conserve diesel, a non-renewable resource. As the adoption of EVs increases, it can lead to a notable decrease in diesel demand. If 30% of diesel-operated buses are replaced by EV-buses, the EV-buses better efficiency compared to ICE Diesel buses will result in a large reduction in energy consumption. The result is tabulated in table 1. This shift not only lowers the demand for fossil fuels but also contributes to reducing operational costs over time. Moreover, it supports environmental sustainability by minimizing harmful emissions and promoting the use of cleaner energy. Transitioning to electric mobility is a crucial step toward achieving energy-efficient and eco-friendly public transportation.

Table 1: Fuel consumption dependency of diesel operated

Division	Buses travel distance (km/day)	Fuel Consumption by bus (liters/day)	Reduction in fuel requirement if 30 % of diesel operated bus are replaced by EV bus
BHUJ	20198	3672.414	2437.69
NALIYA	9838	1696.207	1187.345
NAKHATRANA	9651	1663.966	1164.776
ANJAR	9695	1671.552	1170.086
MANDVI	12374	2133.448	1493.414
MUNDRA	7385	1273.276	891.2932
BHACHUA	6388	1101.379	770.9653
RAPAR	6667	1149.483	804.6381
TOTAL FUEL CONSUMPTION DEPENDENCY	82196km/day	14171.72 liter/day	4,252liter/day

Source: Data Collected from Bhuj Division Depot, Form No 4

5.2 Estimation of Green House Gases (GHGs)

Assessing the air quality impact of diesel-operated public bus services involves analyzing how these

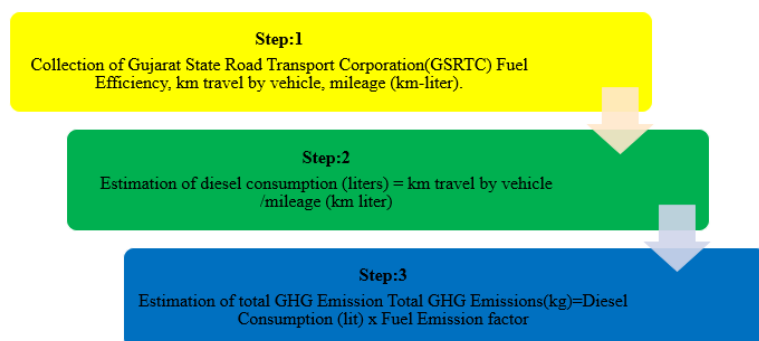


Fig no 3: Flowchart for Estimation of GHGs

emissions affect the air quality in their operational areas. This assessment typically scrutinizes emissions of pollutants like nitrogen oxides (NO_x), particulate matter (PM), carbon monoxide (CO), and hydrocarbons. The

objective is to measure the extent to which diesel buses contribute to local air pollution levels. The computation of GHG emissions for BS VI, BS IV, and EV was quantified by multiplying the flow-chart above. Emission factors are taken from Automotive Research Association of India (A.R.A.I) with the amount of fuel consumed tabulated in table1. Total GHGs emission are quantified and result are tabulated in table below.

Table 2: Difference in GHGs Emissions calculation for BS VI, BS IV, and EV

POLLUTANTS	EMISSION BS IV	EMISSION BS VI	EV	EMISSION REDUCTION BY ADOPTING BS VI	EMISSION REDUCTION BY ADOPTING EV
CH4	0.006	0	0	0.006	0.006
HC	0.086	0.024	0	0.062	0.086
NOX	0.655	0.075	0	0.58	0.655
PM	0.004	0.002	0	0.002	0.004
SO2	0.02	0	0	0.02	0.02
CO	0.28	0.28	0	0	0.28
CO2	7301.27	7301.27	0	0	7301.27

Source: Automotive Research Association of India (A.R.A.I) World Resource Institute (W.R.I.), International Energy Agency. (2024), *Global EV Outlook 2024*. IEA.

5.3 To Explore Fleet Electrification Possibilities

Fleet electrification (i.e., shifting into EV-Buses) involves careful planning and implementation to balance technological, operational, and strategic factors. Evaluating an organization's needs, budget, and operating environment is crucial to determine the feasibility and potential benefits of transitioning

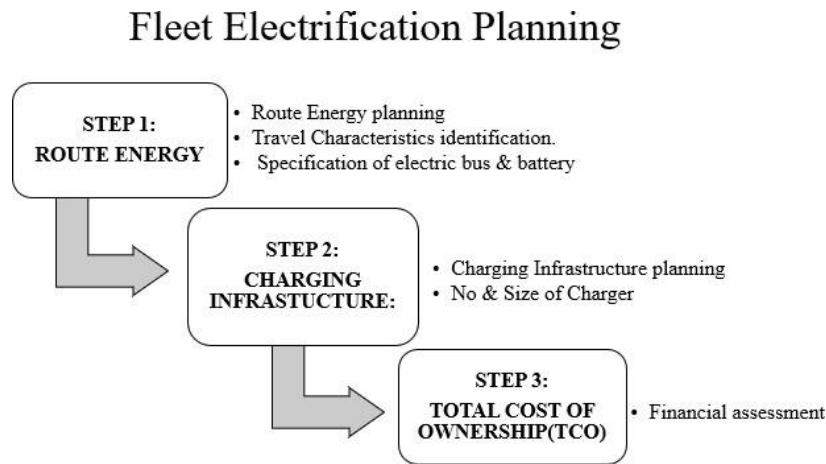


Fig no 4: Fleet electrification planning

to EV-Buses. Successful fleet electrification can lead to significant cost savings, environmental benefits, and an enhanced brand reputation. This shift towards electric vehicles (EVs) within a fleet aims to reduce carbon emissions, improve energy

efficiency, and align with sustainable transportation goals. A TCO was calculated for the project to assess the optimum Fleet Electrification possibilities for existing diesel-operated public transit bus services in the Kutch region. Detailed models were employed to estimate the energy requirements, covering aspects such as route energy consumption, charging infrastructure, and total cost of ownership, that are explained in the subsequent sections.

5.3.1 Route Energy

To make an informed decision, a comprehensive comparison of annual costs between diesel and electric buses was conducted. In this objective we have explore the possibilities of choosing type of bus and type of charger. Selection of various parameters for fleet electrification planning includes analyzing: Route energy planning is essential for maximizing the efficiency and range of EV-Bus fleet. By considering vehicle capabilities, charging infrastructure, driving practices smooth and cost-effective transition to cleaner transportation. In the context of electric buses (EV-buses), route energy refers to the total energy consumption required by a specific bus route. The energy consumption of an electric bus can vary significantly based on factors like average speed of travel, payload weight, weather conditions, vehicle conditioned, etc. tabulated below.

Table 3: Factors associated with route energy

Route energy planning	
Factor associated with route energy planning	Description
Average Speed of travel	Buses with less travel speed and frequent breaking benefit from regenerative braking systems.
Payload Weight	Heavier loads demand more energy, requiring adjustments in route
Weather conditions	Cold temperatures & Intense heat reduce battery range, batteries life & necessitates careful consideration in vulnerable conditions.
Vehicle Condition	Old vehicles consume more power compared to new vehicles.

Source: evACAD (pManifold EV Academy)

Travel Characteristics Identification are crucial in planning the transition of fleets to electric vehicles (EVs) effectively. Understanding these factors optimizes operations, ensures sufficient range, and minimizes costs explain in table no 4. Essential characteristics considered for the present study are route type, total distance, terrain, traffic pattern, etc. Utilizing a data-driven approach, specialized tools, and

stakeholder collaboration ensures smooth operations, maximizes range and efficiency, and propels a sustainable future for fleets. Continuous monitoring and adaptation based on real-world data are vital for optimizing routes and integrating EV-Buses into transportation systems smoothly.

Table 4: Travel characteristics identification

Travel Characteristics Identification	
Factor associated with travel characteristics identification	Description
Route Type	High-speed highways may require higher battery capacity than urban streets.
Total Distance	Long highway stretches require different planning compared to short deliveries within cities
Terrain	Hilly and mountainous regions demand more energy than flat plains.
Traffic pattern	Congestion and travel delay significantly impact energy consumption.

Source: evACAD (pManifold EV Academy)

Specifications of Electric bus and battery are used for batteries propulsion, with size and number based on bus size and range of travel km needs. By considering these factors, planners can select the optimal battery type and design efficient routes for their electric bus fleets. Lithium-Ion batteries was selected for study as it requires minimal maintenance, have no memory effect, and feature a low self-discharge rate, making them ideal for EV-buses. To balance cost and charging frequency, medium-capacity batteries (320 kWh) are considered over smaller (190 kWh) or larger (450 kWh) options. Specifications are listed below in table no 5.

Table 5: Specifications of electric & battery

Specification of electric bus & battery	
Attributes associated with selection of electric battery	Description
Battery useful Life cycles	Generally, bus battery is designed for 10years i.e.3,500 Charging time cycles.

Size of battery	Big battery-300-350kwh Small battery-150-250kwh
Battery cost	22,00,125 (e-Bus Fixed & Big Battery, with subsidy), 4,50,090 (e-Bus Fixed & Small Battery (AC), with subsidy)
Battery DOD (depth of discharge)	Electric buses with larger battery capacities and longer ranges may require less frequent charging.

Source: evACAD (pManifold EV Academy)

5.3.2 CHARGING INFRASTRUCTURE: NUMBER AND SIZE OF CHARGER

Charging infrastructure planning is vital for efficient electric bus operations. Charging speed determines the suitable option, and factors like fleet size, battery capacity, and route requirements influence the



Figure 5: AC Chargers L= 1 Slow; L= 2 Fast; L= 3 or DC fast; L stands for Level
Source: National Institute of Electronics & Information Technology, Calicut

number and size of
chargers, as
summarized in table

no 6. Selection of

EV-charger type for Proposed Study. EV- bus battery charging options include: (1) low-power (40–125 kW), and (2) fast chargers (up to 350 kW). Fast preferred for daytime opportunity charging due to shorter halt times, Chargers rated at 2C can charge a bus battery in 1hr-20minutes, plus 10 minutes for handling. Planning charger number and size requires balancing cost, operational efficiency, and sustainability goals. The factors considered are location and accessibility, charging speed, capacity, cost, etc.

Table 6: Charging Infrastructure planning: Type & No's of Charger

Attributes associated with Charging Infrastructure	Description
Location and Accessibility	Depot charging, mobile chargers or partnerships with existing infrastructure should be considered. Mapping of existing charging stations and planning of routes accordingly

Charging speed	Prioritizing routes with fast-charging stations for long journeys is beneficial. There are typically three levels of charging for electric buses: slow, fast, and rapid.
Cost for utilizing charging infrastructure	Charger Cost - @ 7.5Lakh /Fast Chargerx3 -@ 1.5Lakh/ Slow Charger x 3, Transformer + Connection + Beaker etc=8L, Branding Cost =3Lakh, Software maintenance =0.5Lakh / Year, Technician/ Labour =2.5Lakh / year, Maintenance =4.8Lakh / Year Total Charging infrastructure= capital cost + Total operational & maintenance cost Total cost= 35+4.8= 39.8L (6.63L/1charger)
Number of nodes available for charging	A larger fleet will require more chargers to ensure that all buses can be charged as needed. As per India government norms compulsory 3-fast and 3-slow chargers are to be adopt.

Source: National Institute of Electronics & Information Technology, Calicut

Assumption: [1] Battery sizes and charger capacities follow market standards and government guidelines wherever applicable and are available in the annexure. [2] The analysis assumed a 75% depth of discharge and a 95% charging efficiency. [3] It was assumed that the passengers who traveled in a week were the same. [4] It was assumed that the energy required for the route in a week was the same.

5.3.3 Total cost of ownership

The financial analysis for deploying electric bus was conducted. The life cycle cost assessment (LCCA) of a vehicle is determined by calculating its total cost of ownership (TCO) and incorporating the time value of money. Various factors considered are initial cost, operation cost, maintenance cost, etc. Total cost of ownership for ICE bus and EV bus is tabulated in table no 7. The Total Cost of Ownership (TCO) analysis for the e-bus without subsidy was found to be uneconomical. Therefore, in the subsequent analysis, only subsidized policy buses were considered.

Table no 7: Total Cost of Ownership

Description	Units	ICE Diesel Bus	e-Bus (Without Subsidy)	e-Bus (State Subsidy 50,00,000)
Bus size	meter	9	9	
Bus cost (without battery)	Rs	40,00,000	60,00,000	
Battery cost	Rs	-	72,00,00	
Bus cost (with battery)	Rs	-	1,32,00,000	82,00,000
Charger cost	Rs	-	6,51,193	
Avg. kms run per day	kms/day	220	220	
Operational days per year	days/year	365	365	
Fuel consumption	liter/year	17,844	-	
	kWh/year	-	48,180	
Bus Capitalization Cost $= C_0 \times \frac{i(1+i)^n}{(1+i)^n - 1}$ Where, (Co) = Cost of bus Bus life (n) = 10 years Interest rate (i) = 10% = 0.10	Rs/year	6,50,800	23,37,040	13,92,225
Charging Infra Capitalization Cost	Rs/year	-	1,05,964	
Fuel cost	Rs/year	15,16,778 @ 85Rs/liter	2,64,990 @ 5.5 Rs/kWh	
Manpower cost	Rs/year	12,04,500 @ 15 Rs/km	12,04,500 @ 15 Rs/km	
Bus maintenance cost	Rs/year	6,42,400 @ 8 Rs/km	4,81,800 @ 6 Rs/km	
Total Cost	Rs/year	40,14,659	43,94,294	34,49,479
Total Cost	Rs/km	50.99	56.22	44.46

Source: evACAD (pManifold EV Academy)

5.4 Data Analysis

The Kutch-Bhuj Division comprises eight primary bus stations, housing a combined fleet of 381 buses that collectively travel around 82,916 kilometers each day, serving around 530 stops. On average, these buses transport approximately 1,50,000 passengers daily.

- ❖ Time, Speed, Distance, Grade – from NMEA tool (by travelling in bus)
- ❖ Type & No's of buses, Arrival-departure of bus, Km travel - from time table from ST depot and form no 4 from Bhuj-GSRTC

After data collection, the Vehicle-on-Route Energy for electric vehicles was calculated to analyze

energy consumption on specific routes. The NMEA smartphone app was used to gather time, speed, distance, and gradient data. This data was used as input into the route energy worksheet to determine the energy required to compute each trip where vehicle specification parameters are already entered. Cost of fuel taken from Bhuj depot(84Rs/liter). For finding optimum probability of replacing existing fuel to environment friendly sustainable energy source below given criteria are considered.

Data input in excel sheet for Route Energy calculation

Time-speed
data

Vehicle-
specification

Choose a Cycle
>>>

Bangalore 353 Round Trip

Load Cycle

Inputs (15,000 rows)

Time	Speed	Distance	Grade	Passengers
[s]	[kph]	[m]	[%]	[-]
0	0	0.000	0.000	25
1	0	0.000	-1.801	25
2	0	0.050	-1.801	25
3	0	0.250	-1.801	25
4	0	0.700	-1.511	25
5	0	1.500	-1.244	25
6	0	2.750	-0.994	25
7	0	4.500	-0.756	25
8	0	6.750	-0.527	25
9	0	9.500	-0.305	25
10	0	12.750	-0.090	25
11	0	16.500	0.121	25
12	0	20.750	0.331	25

Parameter	Unit	Value
Vehicle		
Kerb Weight (If unknown, use ICE kerb weight + battery weight below)	[kg]	16425
Payload (Enter 0 or expected luggage load for bus)	[kg]	150
Vehicle Overall Width	[m]	2.58
Vehicle Overall Height	[m]	3.8
Coefficient of Rolling Resistance (CRR)	[N/kg]	0.075
Coefficient of Aerodynamic Drag (CD)		0.64
Driveline Efficiency (losses not accounted for in CRR)		81.0%
Motor		
Maximum power	[kW]	245.0
Average Efficiency		80.0%
Battery		
Select Battery Chemistry		Lithium Nickel Manganese Cobalt Oxide (LiNiMnCoO ₂) - NMC
Battery efficiency		95.0%
Useful Battery Capacity (Spec x Depth of Discharge x Age Fade)	[kWh]	252
Battery Mass	[Kg]	2291
Unit Cell Nominal Voltage	[V]	3.7
Battery Voltage (If unsure, use Nominal Voltage x 10)	[V]	400
Maximum Charging Rate	[/hr]	1
Battery Charge Capacity	[Ah]	630.0
Accessories		
Air Conditioning Power with 40 passengers	[kW]	12
Air Conditioning Power with no passengers	[kW]	2.5
Other Accessories Average Power Consump	[kW]	2.67

Fig no 6: Route energy calculation

Source: evACAD (pManifold EV Academy)

5.4.1 State of Charge (SoC)

First and most important criteria for fleet electrification is State of Charge (SoC). It is a vital indicator in EV-Buses that shows the remaining battery level as a percentage. It helps to estimate driving range and is managed by the Battery Management System (BMS) for safe and efficient operation. Accurate SoC prevents battery damage from overcharging or deep discharging and aids in smart charging and route planning for EV fleets. After finding SoC for each bus trip, priority was given to buses who required minimum opportunity charging or no charging in between route. In this study, 48 buses representing 30% of the fleet were selected for replacement out of a total of 157, 119 buses were

prioritized during the initial screening in the study.

VIH.SCH.NO-19 (FOR 2C CHARGER)						
Inputs						
Start of Schedule	[hh:mm]	5:45	Initial State of Charge	[%]	100%	
Schedule Duration	[hh:mm]	15:40	Depth of Discharge (assume 85% if not known)	[%]	85%	
Reference Battery Capacity Specification	[kWh]	324	Reference Battery Useful Capacity	[kWh]	275.4	
SR. Activity NO	Start of Activity		Duration hh:mm	Energy Exchange in kWh (+ve consumption/-ve charging)	End of Activity	
	Time hh:mm	SoC %			Time hh:mm	SoC %
0	Idle for start of schedule	0:00	100.0%	5:45	5:45	100.0%
1	MUNDRA - BHUJ	5:45	100.0%	1:30	74	7:15 73.1%
2	layover	7:15	73.1%	0:20	0	7:35 73.1%
3	BHUJ - MUNDRA	7:35	73.1%	1:25	71	9:00 47.3%
4	layover	9:00	47.3%	0:20	0	9:20 47.3%
5	MUNDRA - BHUJ	9:20	47.3%	1:25	71	10:45 21.6%
6	layover	10:45	21.6%	0:30	-180	11:15 86.9%
7	BHUJ - MUNDRA	11:15	86.9%	1:25	71	12:40 61.1%
8	layover	12:40	61.1%	0:35	0	13:15 61.1%
9	MUNDRA - BHUJ	13:15	61.1%	1:25	71	14:40 35.4%
10	layover	14:40	35.4%	0:35	-180	15:15 100.0%
11	BHUJ - MUNDRA	15:15	100.0%	1:25	71	16:40 74.2%
12	layover	16:40	74.2%	1:20	0	18:00 74.2%
13	MUNDRA - BHUJ	18:00	74.2%	1:25	71	19:25 48.4%
14	layover	19:25	48.4%	0:35	0	20:00 48.4%
15	BHUJ - MUNDRA	20:00	48.4%	1:25	71	21:25 22.7%
16	Idle for REST of schedule	21:25	22.7%	0:00	-324	21:25 100.0%

Fig no 7: Route energy calculation

Source: evACAD (pManifold EV Academy)

5.4.2 Charging scheduling.

Charging scheduling for EV buses is a crucial aspect of efficient fleet management. It involves planning of timing and duration of charging to ensure that buses are adequately powered. Proper scheduling helps avoid peak-hour charging, reduces downtime, and extends battery life. This approach supports both operational efficiency and sustainable energy use. Here the 119 buses preferred in criteria 1 are scheduled for opportunity charging and overnight charging. In this scenario buses are screen based on minimum period of opportunity charging in which 61 buses were screened for further study. Charging scheduling for one bus has shown in fig no 8.

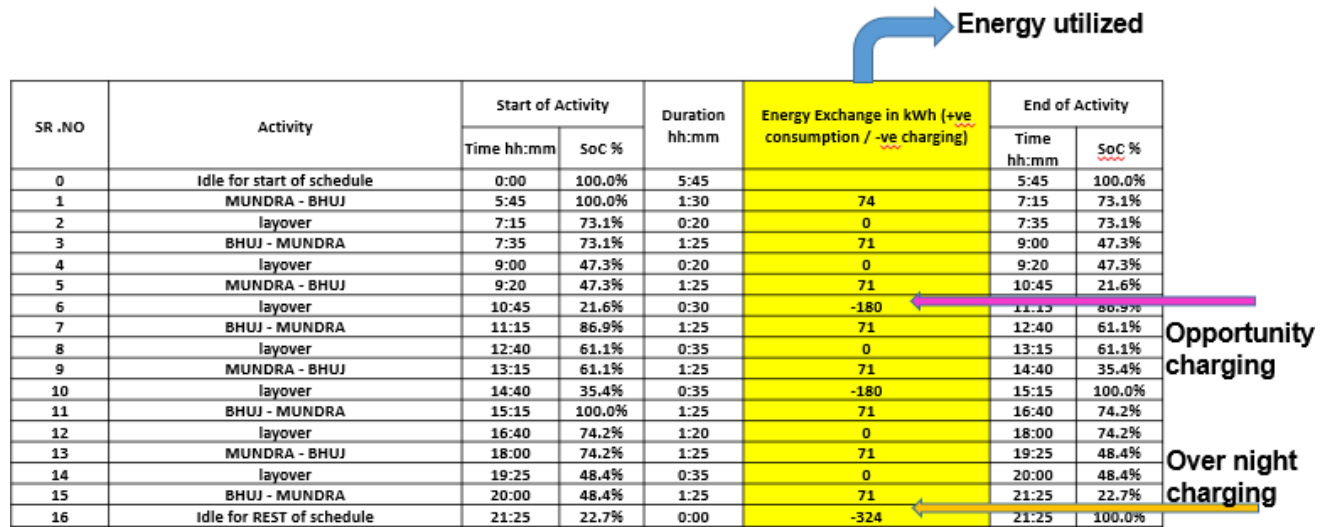


Fig no 8: charging scheduling

Source: evACAD (pManifold EV Academy)

5.4.3 Area availability for charging Infrastructure

The third most important criterion for fleet electrification was the availability of area for charging infrastructure as our main moto was to generate energy from renewable energy rather to consume energy produced from conventional fuel. This availability of area is a key factor in determining the number of solar panels that can be installed, ultimately determining the energy generation needed to drive the vehicles. All the depot has requisite area requirement to fulfill these criteria shown in table 8.

Table 8: Charging infrastructure area availability

Depot	Energy Required for Route (kwh)	Area Available for Charging Infrastructure (sq.mt)	Area utilized For Charging Infrastructure (sq.mt)	Energy Produced from Charging (kwh)
MUNDRA	2640	4756	2456	2742
MANDVI	1140	5761	1062	1152
NALIYA	1200	6704	1120	1214
NAKHATRANA	1140	9524	1062	1152
RAPAR	1200	663	1062	1152
ANJAR	1500	7394	1396	1501
BHACHAU	2880	10239	2680	2881
BHUJ	5920	8651	5508	5921
TOTAL	17620	53692	16346	17715

5.5 Economics assessment for diesel operated and electric vehicle Buses

Net Present Value (NPV) is a financial metric used to assess the profitability of an investment by calculating the difference between the present value of cash inflows and outflows over a period.

$$NPV = \sum_{t=1}^n \frac{C_t}{(1+R)^t} - C_0$$

C_t = Net cash inflow during the period t
 r = Discount rate (rate of return)
 t = Time period (in years) = 10 years
 C_0 = Initial investment

It considers the time value of money, meaning that cash received today is worth more than the same

amount received in the future. A positive NPV indicates that the projected earnings exceed the costs, making the investment potentially profitable, while a negative NPV suggests the opposite. For Different scenario that are 1. Diesel operated bus, 2 electric bus (excluding charging station facility) and 3 electric bus (including charging station facility) calculations are shown below.

Discount Rate= FV/PV

FV = PV (1+rt)

= 82,00,000 (1 + (0.08*10))

= Rs. 14,760,225

Discount Rate= FV/PV

= 14,760,225/82,00,000

= 1.8%

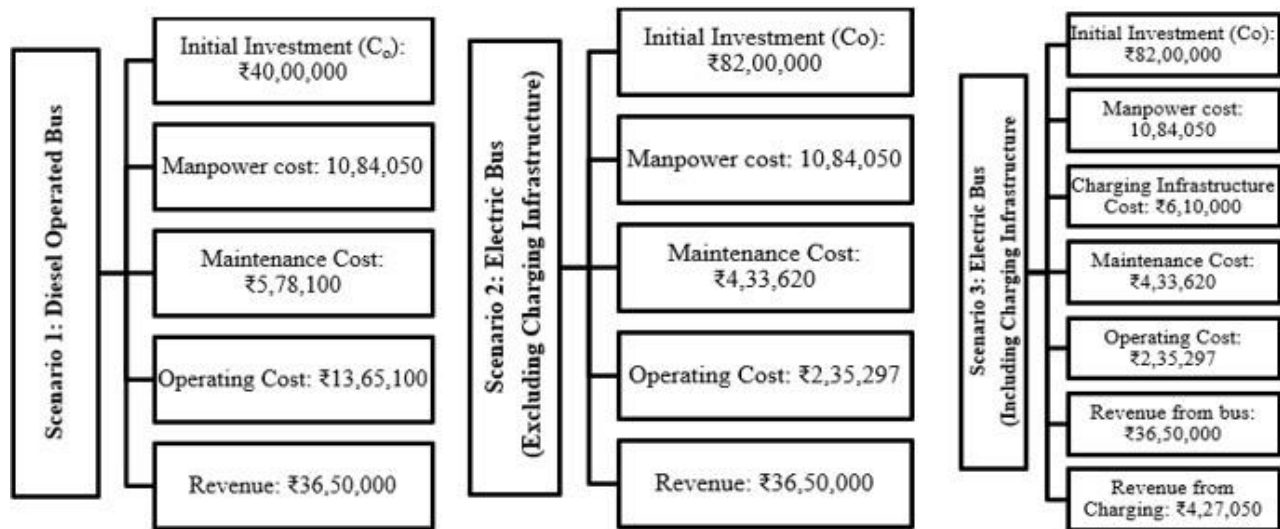


Fig no 9: Net Present Value (NPV) cost consideration for diesel buses and electric buses

Net Annual Cash Inflow (Ct) is the yearly profit a project generates after subtracting all operating, manpower, and maintenance costs from the total revenue.

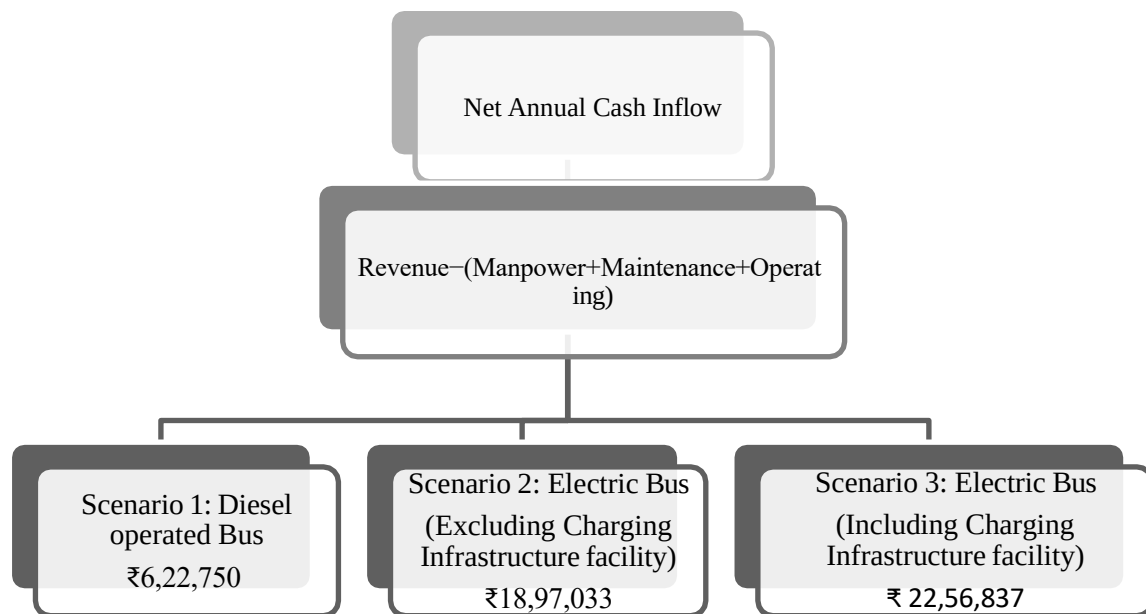


Fig no 10: Net Annual Cash Inflow (Ct) for 3 scenarios

For the three different scenarios—1) diesel-operated bus, 2) at depot where nearby charging facilities are available so in this scenario charging facilities cost are not taken into consideration (electric bus excluding charging station facilities), and 3) whereas at some depot charging facilities are not available therefore new infrastructure facilities are to be developed so in this scenario charging infrastructure cost are taken into consideration (electric bus including charging station facilities) the respective result for different scenario are presented below.

Net present value (NPV) calculation

 SCENARIO 1: DIESEL BUS NPV	 SCENARIO 2: ELECTRIC BUS NPV (WITHOUT CHARGING INFRASTRUCTURE)	 SCENARIO 3: ELECTRIC BUS NPV (WITH CHARGING INFRASTRUCTURE)
$NPV = \sum_{t=0}^n \frac{C_t}{(1+r)^t} - C_0$	$NPV = \sum_{t=0}^n \frac{C_t}{(1+r)^t} - C_0$	$NPV = \sum_{t=0}^n \frac{C_t}{(1+r)^t} - C_0$
$\sum_{t=1}^n \frac{₹6,22,750}{(1+0.018)^t} - 40,00,000$	$\sum_{t=1}^n \frac{₹18,97,033}{(1+0.018)^t} - 82,00,000$	$\sum_{t=1}^n \frac{₹22,56,837}{(1+0.018)^t} - 83,05,964$
 NPV = ₹ 16,52,896	 NPV = ₹90,19,959	 NPV = ₹1,22,86,016

Fig no 11: Net Present Value (NPV) scenarios for diesel buses and electric buses

Internal Rate of Return (IRR) is a financial metric used to estimate the profitability of potential investments. It represents the discount rate that makes the Net Present Value (NPV) of all future cash flows from an investment equal to zero. In simpler terms, IRR is the rate at which the investment breaks even. A higher IRR indicates a more desirable investment, as it suggests that the project is expected to generate a higher rate of return. The respective result for different scenario is presented below.

IRR(Internal Rate of Return)

 SCENARIO 1: DIESEL BUS NPV	 SCENARIO 2: ELECTRIC BUS NPV (WITH OUT CHARGING INFRASTRUCTURE FACILITY)	 SCENARIO 3: ELECTRIC BUS NPV (WITH CHARGING INFRASTRUCTURE FACILITY)
$NPV = \sum_{t=0}^n \frac{C_t}{(1+IRR)^t}$	$NPV = \sum_{t=0}^n \frac{C_t}{(1+IRR)^t}$	$NPV = \sum_{t=0}^n \frac{C_t}{(1+IRR)^t}$
$0 = \sum_{t=0}^n \frac{₹6,22,750}{(1+IRR)^t}$	$0 = \sum_{t=0}^n \frac{₹18,97,033}{(1+IRR)^t}$	$0 = \sum_{t=0}^n \frac{₹22,56,837}{(1+IRR)^t}$
 IRR = 8.98%	 IRR = 19.11%	 IRR = 23.07%

Fig no 12: IRR (Internal Rate of Return) scenarios for diesel buses and electric buses

5.6 Environmental benefit with respect to proposed fleet electrification.

Carbon credits

Carbon credits are certificates allowing organizations to emit a specific amount of CO₂ or equivalent greenhouse gases. Each credit equals one metric ton of CO₂ reduced or removed. Generated through projects like renewable energy, reforestation, or energy efficiency, these credits can be bought, sold, or traded to help meet emission goals. This market-based system supports sustainability and global climate change mitigation. Fleet electrification reduces greenhouse gas emissions by replacing fuel combustion with cleaner electric power. It cuts pollutants like NO_x and PM, improving air quality. Using renewable energy for charging further lowers the carbon footprint. This shift supports climate goals and environmental sustainability. The chart compares the emissions of four key pollutants: Sulfur Dioxide (SO₂), Nitrogen Oxides (NO_x), Methane (CH₄), and Particulate Matter (PM), produced by coal-based electricity and solar panels. The data clearly shows that coal-based electricity is the dominant source of these harmful emissions, while the contribution from solar panels is almost negligible, highlighting the significant environmental benefits of switching to solar energy.

Table 9: External Cost Savings from Pollution

POLLUTANTS	EMISSION FROM DIESEL BUS (BS IV)	EMISSION FROM EV	EMISSION REDUCTION BY ADOPTING EV	EXTERNAL COST SAVING-CARBON CREDIT (2001)	EXTERNAL COST SAVING-CARBON CREDIT (2010)	EXTERNAL COST SAVING-CARBON CREDIT (2020)
CH ₄	0.006	0	0.006	663	150	270
NO _x	0.655	0	0.655	1,19,210	32,750	45,850
PM	0.004	0	0.004	1118	140	240
SO ₂	0.020	0	0.020	2600	500	800
CO ₂	7301.27	0	7301.27	78,85,372	7,30,127	29,20,508
Source				Matthewes et.al.,2001[31]	worldbank.org, www.iea.org ,NFCCC, www.teriin.org [36]	worldbank.org, www.iea.org ,NFCCC, www.teriin.org [36]
Total				80,08,963	7,63,667	29,67,668

6. Achievements with respect to objectives

A study on replacing the GSRTC bus fleet with EV-buses found that the project is both **environmentally beneficial** and **financially viable**. The key outcomes for each objective are as follows:

- **Environmental and Operational Impact:** The study confirmed a significant **decrease in emissions** and a noticeable **improvement in air quality** by reducing the reliance on diesel. The bus was digitized in GIS format, enabling precise mapping and spatial analysis. Decreasing in colour shade shows reduction in emissions. For Kutch (GSRTC), by replacing 30% of BS IV buses with EVs leads to a significant reduction in GHGs emission.

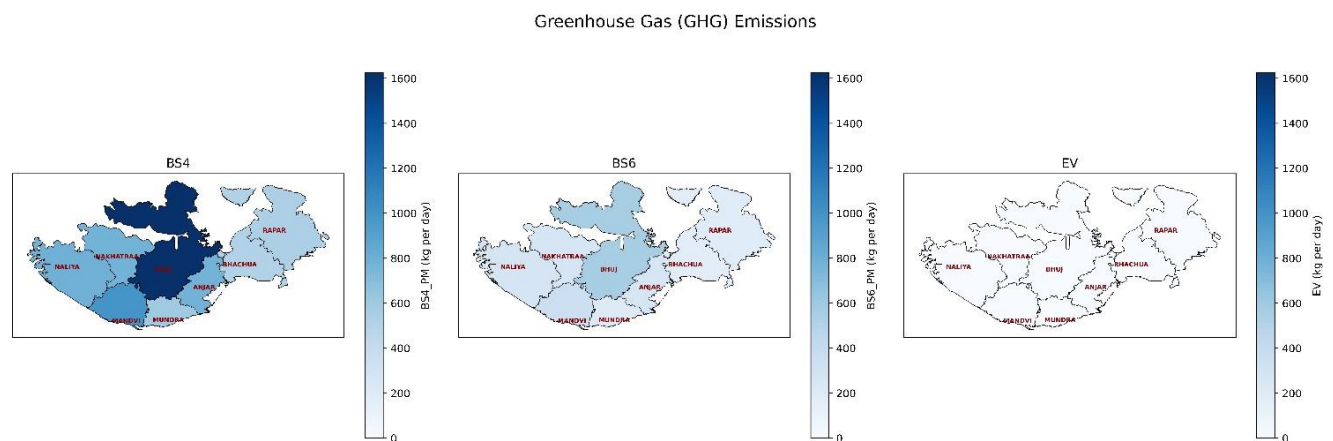


Fig no 13: GHGs Emission difference between BS-VI, BS-IV & EV

- **Fleet Electrification Feasibility:** The analysis identified specific models for future use, concluding **TATA ULTRA** electric bus and **Bharat EV Charger** (AC001 and DC001) are suitable choices for the fleet.
- **Optimal Replacement Strategy:** To successfully replace the fleet, the study established clear criteria for the buses and infrastructure. It was found that **119 buses out of 159** met the necessary state of charge (SoC) criteria in first screening, while in second screening **61 buses** could be

served by the required 30% (**48 buses**) based on a charging schedule. In QGIS software least energy required 48 selected buses are highlighted among 159 bus routes for Kutch region.

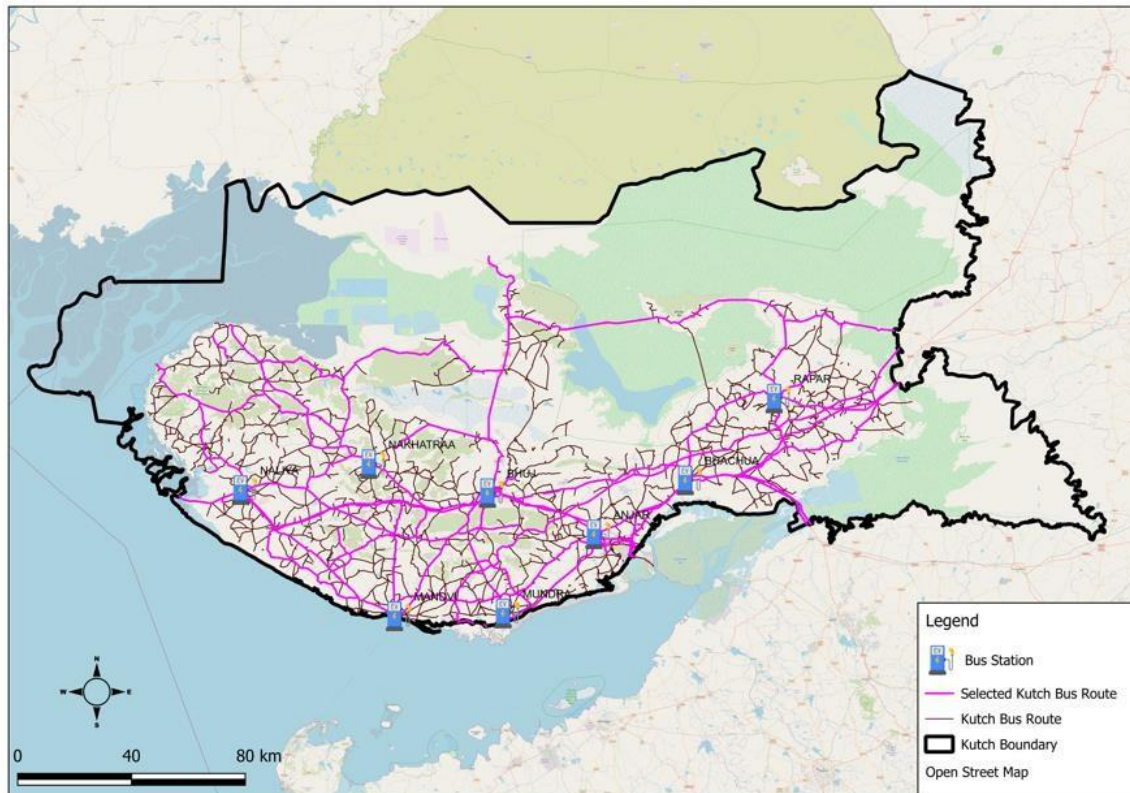


Fig no14: Selected 48 bus route highlighted of Kutch region

- Economic Benefits:** The project's financial analysis showed strong results. The electric bus scenario had a **Net Present Value (NPV) of ₹90,19,959** with an Internal Rate of Return (IRR) of 19.11%. (Excluding charging infrastructure facilities), the NPV increased to **₹1,22,86,016**, and the IRR rose to 22.58% (Including charging infrastructure facilities), making a compelling economic case for the electrification in comparison with diesel fleet shows an NPV of **₹16,52,896** with IRR 8.98. Figure no 15 graph shows total cost comparison between ICE diesel bus Vs EV-bus.

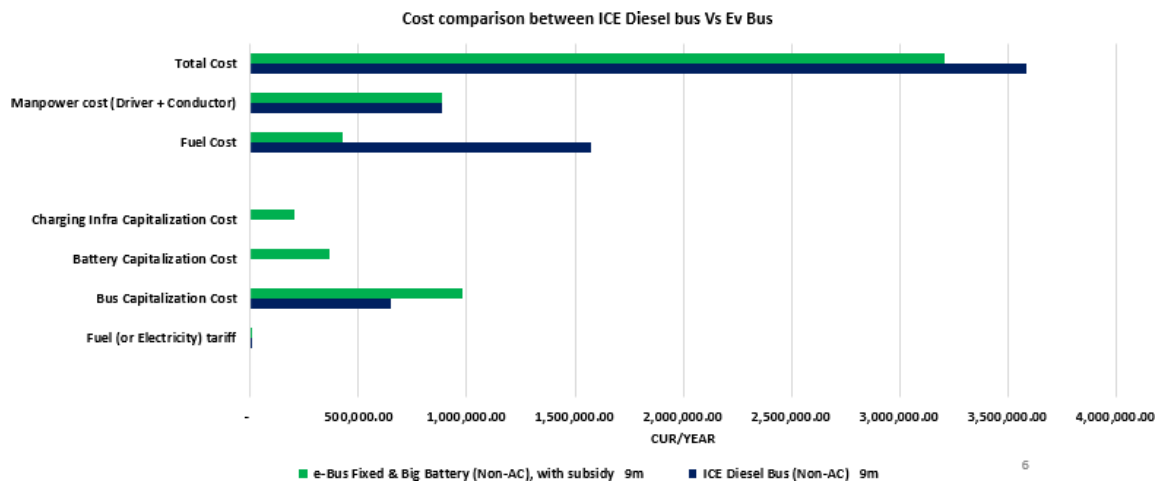


Fig no 15: cost comparison between ICE Diesel bus Vs Ev bus

7. Conclusion

The study on replacing the GSRTC bus fleet with electric vehicles (EVs) demonstrates that the transition is both environmentally sustainable and economically profitable. By substituting 30% of BS- IV diesel buses with EVs, a significant reduction in greenhouse gas emissions and improvement in regional air quality can be achieved, as confirmed through GIS-based spatial analysis. The assessment identified the TATA ULTRA electric bus and Bharat EV Chargers (AC001 and DC001) as optimal choices for future fleet electrification, supported by well-defined criteria for bus selection and charging infrastructure. Operational analysis revealed that 61 buses can effectively function under a 30% (48 buses) replacement strategy, optimizing both energy use and scheduling. Overall, the findings confirm that electrifying the GSRTC fleet is a feasible, sustainable, and economically sound initiative that supports Gujarat's broader goals of green mobility and reduced carbon emissions. The NPV and IRR analysis confirms that electric buses are significantly more profitable and sustainable than diesel buses. The diesel fleet shows an NPV of ₹16.5 Lakh with the Internal Rate of Return (IRR) 8.98, while electric buses achieve NPV ₹90.2 Lakh with the Internal Rate of Return (IRR) 19.11% (excluding charging infrastructure facilities) and ₹1.22 Crore with Internal Rate of Return (IRR) rises to 22.58% (including charging infrastructure facilities). Thus, investing in electric buses with proper charging infrastructure ensures higher financial returns and

long-term environmental and economic sustainability.

. 8. Copies

of papers published and a list of all publications arising from the thesis:

Prajapati, M. L., Gundaliya, P. J., & Sheth, A. (2020). Case study: Solar electric vehicles in India. *IOP Conference Series: Materials Science and Engineering*, 937(1), 012033. IOP Publishing. <https://doi.org/10.1088/1757-899X/937/1/012033>

Prajapati, M. L., Maheshwari, K., & Tanwar, G. (2022). *Fleet electrification planning for Anjar city*. Civil Engineering Department, Tolani F. G. Polytechnic, India.

Prajapati, M. L., & Desai, N. A. (2024). Exploring cost effective fleet electrification possibilities for public transit services in Kutch region. *Current World Environment*, 19(1), 1–15. Enviro Research Publishers. <https://www.cwejournal.org>

9 Patents (if any): NIL

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