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Social Benefit-Cost Analysis for Electric BRTS in Ahmedabad

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Abstract. This research aims to develop a social benefit-cost analysis model for the feasibility assessment of the proposed electric bus rapid transit system project in Ahmedabad, India. An attempt has been made to indicate that the electric bus locomotion, which has a high potential for improving environmental impact can be considered sustainable for urban conglomeration. The realization of sustainable transportation projects is frequently hampered due to the high weightage associated with the financial dimension and somewhat negligence of environmental and social dimensions of the transportation system in the project appraisal process. Therefore, a quantitative analysis of the electric bus transportation system in an urban context was conducted, considering the three major dimensions of sustainability such as economic, environmental, and social. The evaluation was carried out using the present worth analysis of various benefits and costs associated with the implementation of the electric bus rapid transit system in the city. The outcome, as indicated by the value of social benefit-cost ratio, illustrates that such a project can be positively justified from the point of view of the benefits gained by the society as well as profitable returns and value addition of infrastructure investment in the long run. The research contributes by validating that social benefit-cost analysis can be used to evaluate sustainable transportation system appraisals in order to make their realization more favorable.

Keywords: Electric mobility; Life cycle costing; Public transport; Social benefit-cost ratio; Sustainable transport

1. Introduction

In line with the global trend toward the adoption of electric vehicles (EV) for various segments, the government of India, as well as other sectors, have expressed strong interest in fast and large-scale EV adoption. The expression has come in various forms, including reported targets of EV shift (such as 100 % EV by 2030), enabling policies, indigenous manufacturing and approval of electric buses, and other R&D efforts by institutions. Electric buses are one of the possible ways to achieve sustainable public transportation systems. The tripartite model, which includes economic, environmental, and social aspects, is commonly used to assess the sustainability of transportation systems. However, the environmental and social aspects of transportation system project appraisals are frequently neglected. This study aims to conduct a quantitative analysis of an electric bus transportation system in an urban setting while considering all three aspects of

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sustainability. The analysis involves identifying various types of benefits and costs associated with the electric bus transport system in the city, their respective quantification in equivalent monetary terms, and accounting in connection with the time value over the life span of the transport system infrastructure. The evaluation of the electric bus transport system for the selected case city of Ahmedabad, India, as indicated by the social benefit-cost ratio (SBCR) has been presented, and associated deductions have been made to reflect on the significance of considering sustainability benefits of the transport system projects for the appraisal. For the case of the electric bus transportation system, the final social benefit-cost ratio is reflected alongside other comparative indicators. The case studied here is for the bus rapid transport system in Ahmedabad, a city in western India. The paper has the following structure. First, the literature on benefit-cost analysis studies in the transportation sector has been reviewed and presented. After that, the methodology employed in this study was described. The following section shows how to apply this technique to the dataset of the bus rapid transit system in Ahmedabad. The results of the case study are later discussed, and the final section concludes the study from the analysis and presents the futuristic relevance of the study outcome.

1.1. Benefit-Cost Analysis for Transportation Projects: a Literature Review

Historically, benefit-cost analysis has been used to evaluate alternative transportation projects and to aid in decision-making and policy formulations with equity considerations, discounted cash flow techniques, and sensitivity analysis for benefit-cost studies of the future (Barrell and Hills, 1972). It has been recommended for comparing transportation projects cost analysis over traditional benefit-cost analysis which aggregates all monetizable cost components, including “cost savings” (these were referred to as “benefits” in traditional analysis techniques) (DeCorla-Souza *et al.*, 1997). Many researchers have brought into discussion the challenges associated with benefit-cost analysis as a technique and the capacity of benefit-cost analysis (BCA) frameworks in decision making. The deficiency such as incomplete analysis, uncertainty, and difficulty in effect estimation (Mouter, Annema, and Van-Wee, 2015), the sensitive question of uncertainties in cost-benefit assessments and their influence on public infrastructure investment decisions (Asplund and Eliasson, 2016) have been addressed in the context of a benefit-cost method for project appraisal. As well as the methodological issues and corresponding models for ex-ante project assessment of cost-benefit analysis for capital intensive infrastructures (Florio and Sirtori, 2016), critical questions on the importance of qualitative impacts including social, human life, natural, and built environment over quantitative assessment (Hickman and Dean, 2017) and on the equity perspectives (Martens and Floridea, 2017). Sheth and Sarkar (2020) were the primary proponents of the socio-economic feasibility analysis of the mass rapid transit system (MRTS) projects of Ahmedabad a city in western India. Their study revealed that with government, sustainable MRTS projects are techno-economically feasible in an emerging economy like India.

Other researchers have commented on the BCA technique as applied to assess larger-scale economies and organizational changes in infrastructure projects such as public urban transit (Viton, 1993), as well as the microeconomic and macroeconomic analyses tools for the transportation sector as an attempt to achieve broader (regional) economic benefits from new transportation investment (Anas, Tamin, and Wibowo, 2016). A broader approach for evaluating the economic benefits of urban infrastructure with an integrated four-dimensional approach accounting for the effects of consumption investment, government purchase effect, and external demand (Sun and Cui, 2018a) reflected the potential of coordinated development. The same was illustrated (Sun and Cui, 2018b) in terms of economic, social and environmental benefits. In the context of mass rapid transit systems, it has been demonstrated that indirect social effects such as ridership can contribute to improved benefits (White, Turner, and Mbara, 1992). On the other hand, subsidies and public ownership models for mass transit can lead to wasteful cost escalation (Pucher and Marksted, 1983). It has also been recommended that benefit-cost analysis be used for regional public transport planning in healthy economies (Johansson *et al.*, 2017). The social, economic, and environmental impacts of public transportation have also been reviewed for meeting the sustainability goals of cities and regions, and recommendations on the sustainable performance of public transit have also been made (Miller *et al.*, 2016). With the advent of electric vehicle technology, it was critically observed that the EV policies in developed countries lack sufficient attention from economists while addressing social costs and benefits (Massiani, 2015) and where such analysis has been performed, the economically beneficial time frame was predicted to be as much as another 45 years for EV and another 95 years for Fuel cell vehicles (FCV) (Ito and Managi, 2015). The benefit-cost analysis for comparing the profitability of electric and gasoline tax is also quantitatively concluded that the electric taxi could be profitable when gasoline price goes up, and battery price goes down (Wang *et al.*, 2015). Despite the numerous obstacles that prevent successful implementation of electric vehicles, the necessity of green vehicles has been emphasized (Sadek, 2012). A recent business case in favor of EVs and ideas to overcome technological and market penetration barriers have also been developed. It has also been proved that the successful realizations of such projects and the creation of business value are dependent on business strategies and benefits realization management (Serra and Kunc, 2015). With this background of benefit-cost analysis reviewed in the context of the transportation sector, an attempt has been made to perform the social benefit-cost analysis (SBCA) for the electric bus transport project in Ahmedabad.

2. Methods

Figure 1 depicts the methodology used to calculate the social benefit-cost ratio. For the present case study, SBCA for the electric bus rapid transit system (e-BRTS) has been calculated for the proposed network of 185.1 km, which includes eight routes. The benefits and costs and the net value of benefits are identified in Figure 2. The following section illustrates the values and bases for monetary and non-monetary benefits and costs data. . The present value of the benefits and costs is computed for 25 years life cycle and a 12 % discount rate. The analysis is then presented, including the computation of the social benefit-cost ratio. Many researchers consider a 12% discount rate a standard percentage, including Ranganath and Sarkar (2021), Sarkar and Sheth (2021). A life cycle of 25 years is a common practice in BRTS projects (Sarkar and Sheth, 2021).

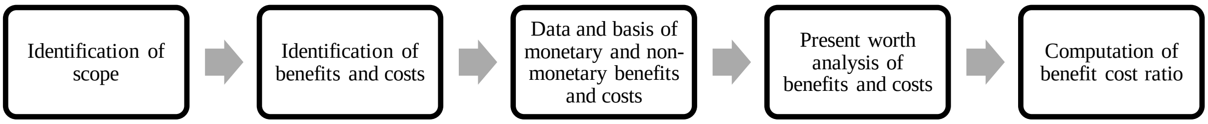


Figure 1 Methodology for computing SBCR

3. Case Study and Analysis

3.1. Scope

The analysis has been performed for the case data of the bus rapid transit system in the city of Ahmedabad (popularly known as Janmarg, incepted in 2009), which currently utilizes diesel as the major fuel for bus locomotion. It is India's largest BRT operation, transporting approximately 0.14 million passengers using nearly 250 buses on a dedicated 97-kilometer route through 158 stations daily. Recently, the government of India approved financial assistance for the purchase of 40 electric buses for the city under the faster adoption and manufacturing of (hybrid &) electric vehicles (FAME) Scheme, Department of Heavy Industry, Ministry of Heavy Industries, and Public Enterprises. Following this, the city transportation authority intends to appoint and deploy an operator /original equipment manufacturer (OEM) on a gross cost contract basis for the procurement, operation, and maintenance of 40 Midi AC electric buses. Table 1 illustrates the routes selected for this first implementation; thus, analysis has been applied within this scope.

Table 1 Route details for proposed e-BRTS

Sr. No.	Route no.	Origin – Destination	Route Length (km)	No. of buses on the route	Daily vehicle km
1	1	Maninagar to Ghuma Gam	21.2	28	3732
2	1	Ghuma Gam to Maninagar	19.9		3631
3	2	Sola Bhagwat to Maninagar	22.2	14	3833
4	2	Maninagar to Sola Bhagwat	22.9		4149
5	3	Iscon to Naroda Gam	22.4	22	3833
6	3	Naroda Gam to Isckon	22.2		3833
7	101	RTO Circle to RTO Circle (Circular route 101)	27.1	12	4769
8	201	RTO Circle to RTO Circle (Circular route 102)	27.2	12	4769
		Total route length	185.1		

3.2. Data sources

The monetary and non-monetary benefit and cost data have been obtained or derived from various sources such as (a) A-BRTS office primary consultation, (b) BRTS publications, (c) Working paper on SBCA of Delhi metro by Murty *et al.* (2006) (d) Road user cost study by Swaminathan and Kadiyali (1983) (e) Publication by electric mobility alliance (2017) (f) Publication by GGGI and CSTEP (2016) (g) Publication by the Department of food and rural affairs (UK) (h) Publication by the Ministry of urban development, India (2016) (i) Publication by the Ministry of road transport and highways, India (2015) (j) Publication by the International council on clean transportation (2009) (k) Publication by the Ministry of heavy industries and public enterprises, India (2017) (l) Publication by Energy alternative India (2014) and (m) Publication by the India energy portal (2013).

3.3. Benefits estimations

The following sections provide overviews of the potential benefits of e-BRTS.

(a) Revenue: The revenue benefits for the e-BRTS consist of ridership and advertisement revenue.

(b) Savings in vehicle operating costs: Two factors are expected to reduce vehicle operating costs: (i) Non-operation of diverted vehicle(two-wheelers) and (ii) Non- operation of diesel buses.

(c) Environmental benefits: The environmental benefit includes a reduction in tailpipe emissions and better air quality, as well as a reduction in noise pollution. Both benefits contribute to improving the community's health by using public transportation and living in an area where public transportation is available. The environmental benefits are non-monetary benefits and have been computed based on monetization data available in mentioned sources.

(d) Benefits to users due to savings in travel time: The e-BRTS operates on a dedicated corridor and results in higher speeds and reduced travel time for the users. The vehicle km of diverted traffic has been estimated as a product of no. of diverted vehicles, the average trip length of each vehicle, and the no. of trips made by the vehicle. The travel time savings of diverted commuters are based on the trips saved due to the mode shift and the time value for work and non-work trips. The monetary value of travel time is derived from the sources mentioned..

(e) Benefits from reduction in accidents: There is sufficient statistical evidence that suggests that BRTS Ahmedabad has facilitated in reduction of road accidents mainly because of the corridor working against wrong side driving habits. The cited data shows relationships between the number of diverted vehicles and the number of fatal, injury, and property damage accidents. The benefits of reducing are calculated by first applying the relationship between lowered diverted vehicles and related accidents and then by computing the product of decreasing accidents with related compensation costs.

(f) Benefits from non-consumption of fossil fuel: The benefits due to savings of non-consumption of fossil fuels constitute those that are contributed by the diverted traffic (2-wheelers and cars) and the ceasing of the diesel BRTS. These have been estimated as a product of the total vehicle km traveled due to various modes, their respective mileages, and unit cost of fuel.

3.4. Costs estimations

(a) The following are overviews of the costs that are expected to be incurred as a result of the e-BRTS. Cost of corridor development include capital costs associated with developing BRTS corridors, BRTS bus shelters, depots, sliding doors, terminals, and, hardware / software for intelligent transport system.

(b) The cost of charging infrastructure includes the charging stations required for the electric buses, which are assumed to be conductive charging stations currently popular in other countries with electric bus mobility. The charging infrastructure standards in India are still evolving, but market cost based on charging specifications reported in other literature has been referenced. One charger per bus is assumed based on charging time and bus scheduling requirements.

(c) The capital cost of bus procurement includes the capital expenditure incurred, which has been accounted based on the current market price and a subsidy sanctioned by the Indian government for the city e-BRTS.

(d) The annual infrastructure maintenance cost (civil) involves the annual BRTS corridor maintenance cost for the civil components, estimated using a recent BRTS publication.

(e) The replacement cost of ITMS infrastructure comprises the costs of substituting ITMS equipment (hardware, software, and fiber optic electronics), which are also approximated from recent BRTS publication.

(f) The cost of bus replacement is considered the same as the capital cost of buses and is expected to occur at the end of 15 years in the analysis.

(g) The cost of battery replacement includes the electric bus batteries, which have a high storage capacity and have been identified as a significant cost component of the system. Numerous battery technologies are available on the market, depending upon variations in anode, cathode, and electrolyte combinations. Lead acid batteries, nickel-based aqueous batteries, and lithium-ion batteries are all standard technologies, with lithium-ion being the most commonly used in present electric vehicles.

(h) The cost of system operation and maintenance is predicted to include the cost of electricity, maintenance, and skilled and unskilled labor. The city has adopted a gross cost contract model for procurement, operation, and maintenance of e-BRTS Ahmedabad. The supplier (TATA Motors) would operate and maintain the bus at the cost of INR 59 per km.

(i) The cost of additional electric power generation, transmission and distribution includes the transition to electric mobility for buses means extra power or electricity required from the grid, which will be transferred to the vehicle through charging stations. The energy requirement of a typical electric bus is estimated to be around 325 kWh, and the total power requirement has been determined based on the size of the fleet. Although the electricity grid is currently supplied by a mix of thermal and renewable energy, the cost of future power is based on captive solar power plant generation. In order to account for the solar power plant size and cost required for the e-BRTS fleet (88 buses), the city's insolation level is assumed to be 5.8 kW/sq.m./day (Ranganath and Sarkar, 2021; Sarkar and Sheth, 2021). The required energy and system size is calculated as follows.

Energy Requirement = 88 x 325 = 28,600 kWh

System Size = 28600 x 1.3 / 5.8 = 6,410 kWp

For a given size, the cost of solar captive power plant installation is estimated based on price per unit data provided in Indian sources. About 95 % of the cost of transmission and distribution (T&D) of the electric power constitutes the capital cost of T&D infrastructure. The additional power's capital cost for transmission and distribution infrastructure is estimated based on Indian energy publications. The operating expenses are highly insignificant and therefore not accounted for. It can be seen that Figure 2 schematically represents the benefits of the e-BRTS project, and Figure 3 schematically illustrates the costs of the e-BRTS project. Furthermore, Figure 4 depicts the cash flow diagram of the expenses, while Figure 5 depicts the cash flow diagram of the e-BRTS project's benefits.

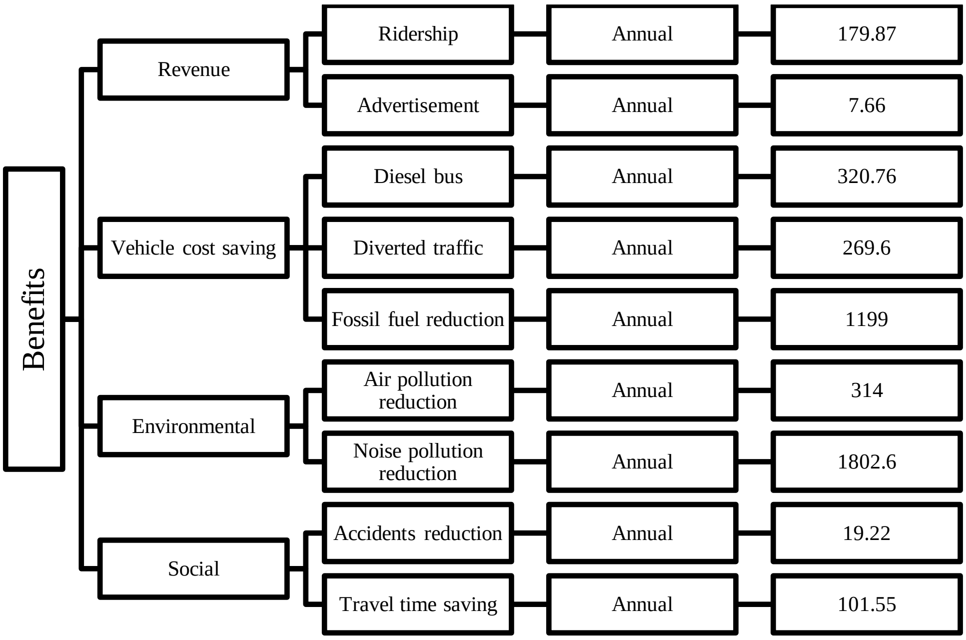
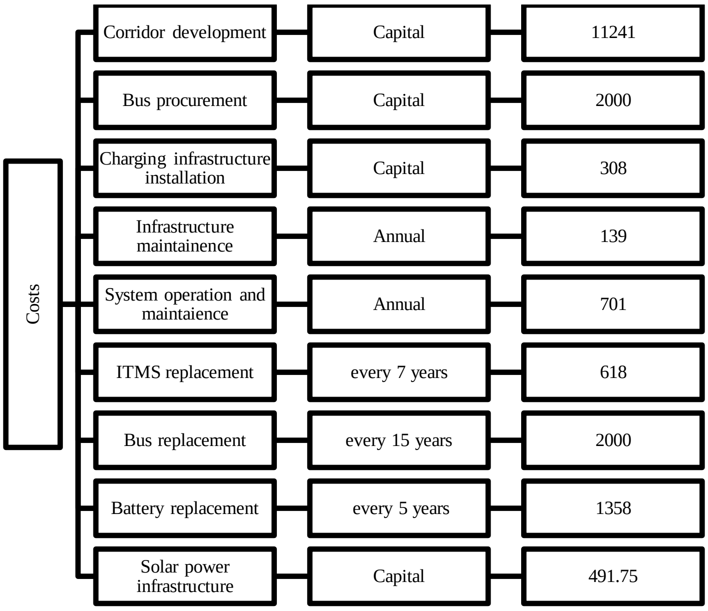


Figure 2 Types of benefits, recurrence, and values (in Million INR) for the e-BRTS project



Costs		
Corridor development	Capital	11241
Bus procurement	Capital	2000
Charging infrastructure installation	Capital	308
Infrastructure maintainence	Annual	139
System operation and maintaience	Annual	701
ITMS replacement	every 7 years	618
Bus replacement	every 15 years	2000
Battery replacement	every 5 years	1358
Solar power infrastructure	Capital	491.75

Figure 3 Types of costs, recurrence, and values (in Million INR) for the e-BRTS project

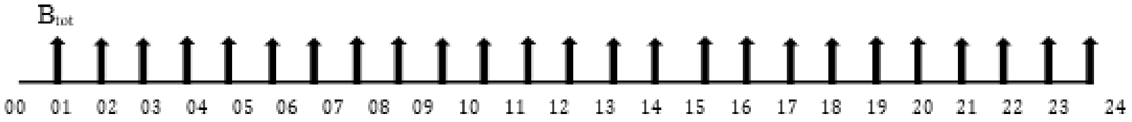


Figure 4 Cash flow diagram of benefits of the e- project

$B_{tot} = B_{RR}+B_{AR}+B_{VCSB}+B_{VCSD}+B_{RFFC}+B_{APR}+B_{NPR}+B_{AR}+B_{TTS}$

Where,

B_{tot}: Total annual benefits

B_{RR}: Benefits due to ridership revenue

B_{AR}: Benefits due to advertisement revenue

B_{VCSB}: Benefits due to vehicle cost saving of bus traffic

B_{VCSD}: Benefits due to vehicle cost saving of diverted traffic

B_{RFFC}: Benefits due to reduction in fossil fuel consumption

B_{APR}: Benefits due to air pollution reduction

B_{NPR}: Benefits due to noise pollution reduction

B_{AR}: Benefits due to accident reduction

B_{TTS}: Benefits due to travel time savings

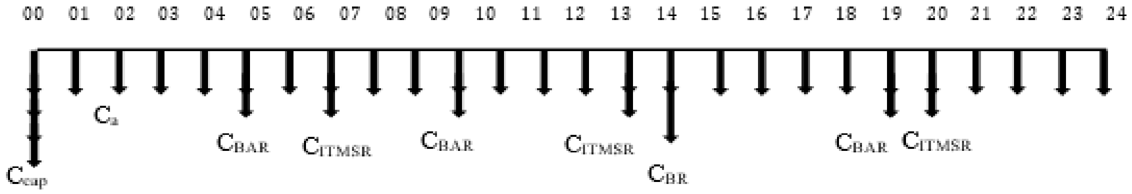


Figure 5 Cash flow diagram of costs of the e-BRTS project

$C_{cap} = C_{CD}+ C_{BP} + C_{CI} + C_{SPI}$

$C_a = C_{IM} + C_{SOM}$

Where:

C_{cap}: Capital costs

C_a: Annual costs

C_{CD}: Cost of corridor development

C_{BP}: Cost of bus procurement

C_{CI}: Cost of charging infrastructure installation
C_{SPI}: Cost of solar power installation
C_{IM}: Cost of infrastructure management
C_{SOM}: Cost of system operation and maintenance
C_{ITMSR}: Cost of ITMS infrastructure replacement
C_{BR}: Cost of bus replacement
C_{BAR}: Cost of battery replacement

Considering uniform series present-worth, the present value of the annuity (P/A) has been obtained by the following relationship:

$$\frac{P}{A} = \frac{(1+i)^n - 1}{i * (1+i)^n} \tag{1}$$

The single payment present-worth has been obtained by the following relationship:

$$\frac{P}{F} = \frac{1}{(1+i)^n} \tag{2}$$

For the analysis case, the discount rate, i is 12 % and the period of evaluation, n is 25 years. The total annual benefits account for INR 4214.26 million (USD 54.03 million), corresponding to a present net of INR 33,053 million (USD 423.76 million).

The total capital cost account for INR 12040.75 million (USD 154.37 million), and the annual cost accounts for INR 840 million (USD 10.80 million). While the one-time battery replacement cost for 5, 10 and 20 years is INR 1358 million (USD17.41million) and the one-time cost of bus replacement at 15 years is INR 2000 million (USD 25.64 million). The one-time cost of ITMS infrastructure replacement at 7, 14 and 21 years is INR 618 million (USD 7.92 million). The total present-worth of these costs is 22,806.21 million (USD 292.39 million). Thus, the social benefit-cost ratio of the proposed e-BRTS for a 12% discount rate and 25 years life cycle is 1.45. Similarly, the social benefit-cost ratios at 8 %, 10 %, and 18 % discount rates are computed to be 1.72, 1.58, and 1.15, respectively.

4. Result and Discussion

The social benefit-cost analysis study carried out for a life cycle of 25 years for the e-BRTS network under consideration in Ahmedabad revealed a benefit-to-cost ratio greater than unity, indicating that it may be a positive investment for the city if the various socio-economic factors are also evaluated and considered. Figures 5 and 6 demonstrate the distribution of the present value of multiple benefits and costs, respectively.

Significant environmental benefits of 50 % are anticipated for the case, followed by benefits due to a reduction in fossil fuel consumption of 29 %. It is further observed that a considerable cost is needed for developing such an infrastructure of 51 %. Another major component involved is the transaction system operation and maintenance cost of 24 %. Certain benefits are associated with the inherent existence of the BRTS in general, such as revenue generation, diverted traffic VOC, travel time savings, and accident reduction. They will continue remaining as benefits for the e-BRTS as well. However, the significant amount of additional benefits such as pollution reduction, savings in fossil fuel consumption, and VOC savings of diesel buses, that needs to be captured. Similarly, the costs associated with implementing the BRTS in general, such as corridor development, infrastructure maintenance cost, intelligent transport management system (ITMS) equipment replacement costs, and system operation and maintenance costs are significant and unavoidable. Some additional costs of charging infrastructure development, bus procurement and replacement, battery replacement, and electric power generation are also expected for the e-BRTS to be in place. The most significant future cost component envisaged is the cost of the bus, charging stations, and battery replacement, which constitutes 15-20 % of the total life cycle cost. Therefore, if the benefits and costs were to be evaluated in terms of existing and future expectations, the additional benefits due to e-BRTS which constitute 86 % of the benefits (INR 28,520 million or USD 365.64 million) far outweigh the costs due to e-BRTS which constitute only 20 % of the additional costs (INR 4,515 million or USD 57.88 million). This is a significant finding as it supports the fact that the e-BRTS can lead to the value addition of what has already been invested in existing BRTS. It can be seen that Figure 6 represents the existing and additional benefits of the e-BRTS while Figure 7 represents the existing and additional costs of the e-BRTS.

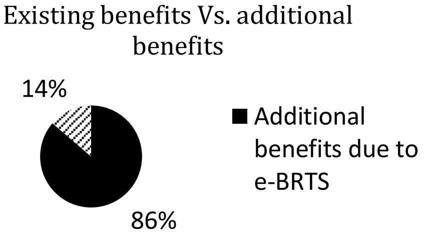


Figure 6 Existing and additional benefits of the e-BRTS

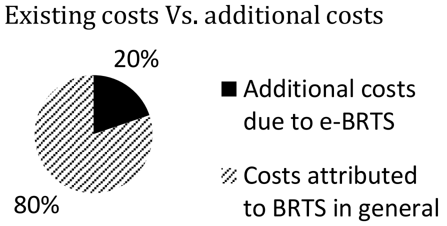


Figure 7 Existing and additional costs of the e-BRTS

4. Conclusions

This research presents a comprehensive social benefit-cost analysis for assessing the feasibility of implementing an electric bus transportation system. The analysis has been applied to the case of Ahmedabad, India, where the electric bus system is being proposed along eight routes. The fundamental rigor behind electrifying bus transport is its sustainability values. This study uses precise quantitative analysis to justify the concept. Thus, it contributes by illustrating that the social benefit-cost analysis may be used as a tool for supporting both sustainability concerns and appraisals of such otherwise financially less viable transport projects. According to the analysis, it has been concluded that the electric BRTS implementation for the selected network in the city is favourable as the present worth of benefits exceeds the costs. It has been observed that the benefit-cost ratio for a discount rate of 12 % and life cycle of 25 years is found to be 1.45 and the internal rate of return is estimated at greater than 18 %. And also, the benefit-cost ratio at 8 %, 10 %, and 18 % discount rates are estimated to be 1.72, 1.58, and 1.15, respectively. It has also been observed that road users are the main beneficiaries. Life cycle environmental benefits can represent up to 50% of the benefits which sums up to INR 16,600 million (255 million USD) for the studied case. The major cost, 51% involved in the implementation of an e-BRT project, is infrastructure development, which amounts to INR 11,549 million (USD 178 million) for the studied case, with corridor development being the major subcomponent. A significant finding of the detailed existing and future cost-benefit components for the context-specific case studied revealed that the e-BRTS additional benefits foreseen due to e-BRTS which is 86% or INR 28,250 million (USD 435 million), far outweigh the additional costs, which is about 20% or INR 4,514 million (USD 70 million) incurred for its successful implementation. This is considered valuable to the city's efforts and investment in various socio-economic causes. Even though high financial returns are not expected from the e-BRTS, the project can be called sustainable due to the numerous benefits to road users and its fruitful socio-economic perspectives. The scope of future research may address efforts to develop a more robust and self-sustaining financial model that may enable electric bus mobility in Indian cities.

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