GOVERNMENT OF INDIA
MINISTRY OF HOUSING AND URBAN AFFAIRS

OPERATIONAL ECONOMICS OF ELECTRIC BUSES IN CONTEXT OF MEGA CITY OF DELHI

Mohd Anas (Ernst & Young)
Prof. Dr. Sanjay Gupta (SPA, Delhi)

UP METRO

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Background

Emission

The transport sector contributed to approximately **15%** of the total emissions by energy sector, where, road transport has been the major contributor **(88%)** resulting in **142 million tonnes** CO_2

Dependence on Oil Import

India is the third largest importer of crude oil in the world. Spend close to **$85bn** on oil imports. India is expected to spend **$550bn** on imported fuel for passenger mobility. That is close to one-fourth of its current annual GDP.

Air Pollution

In recent years owing to an increasing phenomena of pollution levels observed in cities in India owing to increased motorization rates there is a greater emphasis on adopting low carbon emitting modes in urban mobility in comparison to internal combustion engine vehicles

Research Need

New Mobility Paradigm

- System Integration — Share
- Shared Infra Development — Electric
- Scaled Manufacturing — Connected

“Making India’s passenger mobility shared, electric, and connected can cut its energy demand by 64% and carbon emissions by 37%”

Focus of Niti Ayog is on **Public transport and Hired Modes**

Recently in **FAME2 Scheme, 3545 crores out of 9643 crores** have been allocated for demand incentive for electric buses.

A pilot project has been launched under which **11 cities** have been provided with subsidy to procure **520 electric buses** for their respective public transportation fleets

“However there are knowledge gap when it comes to understanding the adoption of electric buses for public transit. This study is an attempt to understand the best procurement and charging operation models for electric buses in India”

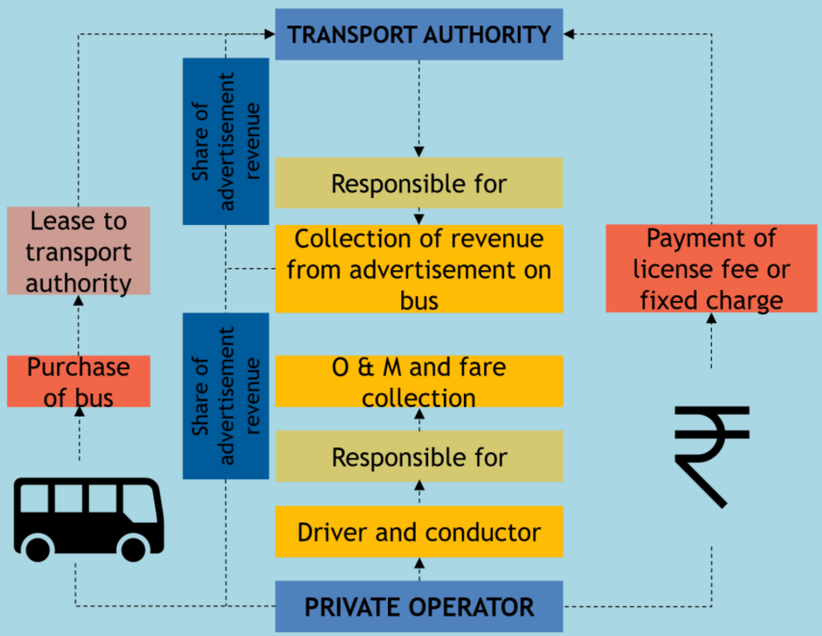
Objectives

1. To assess the role and importance of electric bus in urban mobility
2. Analyse various methods and practises for quantification of electric bus operation in urban areas
3. To assess operational economics of electric buses in urban areas which included the lifecycle cost, charging station and battery swapping station cost
4. To assess the adoption of electric bus operation in Delhi
5. To propose guidelines for implementing EV policy adoption in various cities in India.

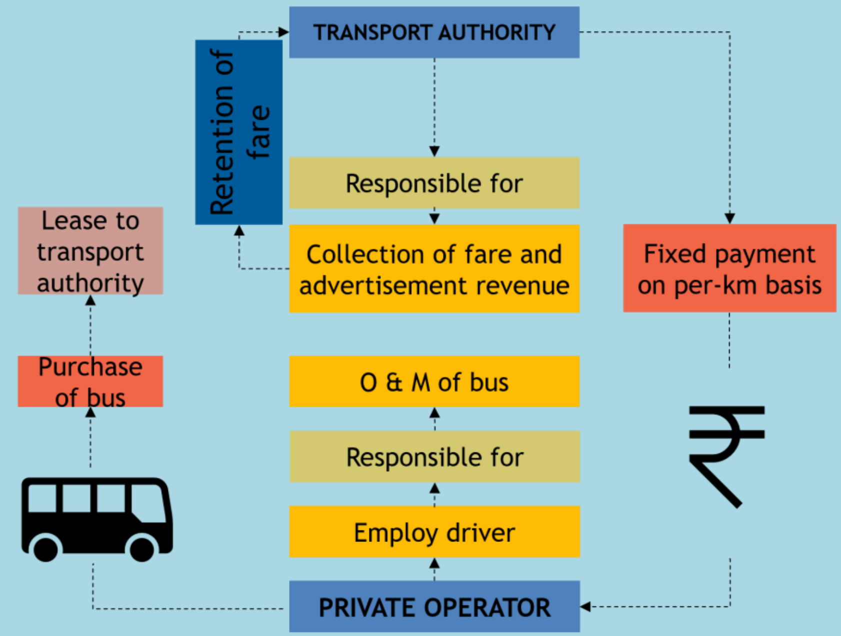
LITERATURE REVIEW

Procurement Models

Net Cost Model



Gross Cost Model



Gross Cost Model: Eliminating Capex While Lowering Opex

The operator only assures **a fee per KM** with an assurance of a given number of KMs everyday with the contract **running for a set number of years**

The contracts are bankable due to the fact that **lower opex allows for enough cashflows to service EMIs.**

Defined contracts allow for **financing on longer tenures**

Life Cycle Cost

- **The lifecycle is often referred to as the sum of all the costs incurring during an asset's useful life and allows for a more appropriate cost benefit analysis.**
- The 'realistic appraisal' conducted through LCC analysis is reinforced by considering the time value of money.

Total LCC = Capital Cost + $\sum_{i=1}^{n}$**(*Operating Cost for given year i + Maintenance Cost for a given year i)* + Vehicle Disposal Cost**

Life Cycle Cost Parameters	Capital Cost **Bus is procured with a debt of 80% and equity of 20%.** Different cost components are listed below: ❑ Annual debt repayment on bank finance @ 10% interest ❑ Annual debt repayment on equity @ 15% interest	Operational Cost ❑ Electricity/Fuel cost ❑ Driver ❑ Other staff (Manager, secretarial, cleaner)
Maintenance Cost ❑ Tyres and tubes ❑ Battery replacement ❑ Spare parts ❑ Annual Maintenance Charges ❑ Overheads	Disposal Cost ❑ Salvage value @ 15% of vehicle cost ❑ Battery recycling cost	External Cost ❑ Human Health Cost

COMPARISON OF DIFFERENT ELECTRIC BUS BY DIFFERENT MANUFACTURERS

S. No	Specification	Manufacturer	Length of Bus	Type of Bus	On Board Battery (in KWH)	No of Seats	Range	Indicative Benchmark Price (in Lakh ₹)	Subsidy @ ₹20,000 per kWh (in Lakh ₹)	Cost per Metre (in lakh ₹)	Cost per KM Range (in lakh ₹)	Cost per Seat (in lakh ₹)	Cost per KWH (in lakh ₹)
1	Length: 9m AC Range: 150 km Floor Height: 900 mm Seating Capacity: 31 Battery Capacity: 125KWH	Tata Motors Ltd	9	AC	125	31	150	117	25	13.0	0.8	3.8	0.94
2	Length: 9m AC Range: 200 km Floor Height: 650 mm Seating Capacity: 31 Battery Capacity: 162KWH	Goldstone - BYD	9	AC	162	31	200	155	32.4	17.2	0.8	5.0	0.96
3	Length: 9m Non AC Range: 200 km Floor Height: 650 mm Seating Capacity: 31 Battery Capacity: 162KWH	Goldstone - BYD	9	Non AC	162	31	200	144	32.4	16.0	0.7	4.6	0.89
4	Length: 9m AC Range: 80 km Floor Height: 890 mm Seating Capacity: 27 Battery Capacity: 124KWH	VE Commercials Ltd	9	AC	124	27	80	139.83	24.8	15.5	1.7	5.2	1.13
5	Length: 12m AC Range: 150 km Floor Height: 900 mm Seating Capacity: 40 Battery Capacity: 125KWH	Tata Motors Ltd	12	AC	125	40	150	135	25	11.3	0.9	3.4	1.08
6	Length: 12m AC Range: 300 km Floor Height: 400 mm Seating Capacity: 40 Battery Capacity: 250KWH	Goldstone - BYD	12	AC	250	40	225	200	50	16.7	0.9	5.0	0.80
7	Length: 12m AC Range: 300 km Floor Height: 400 mm Seating Capacity: 40 Battery Capacity: 250KWH	Goldstone - BYD	12	Non AC	250	40	225	186	50	15.5	0.8	4.6	0.74

COMPARISON OF DIFFERENT ELECTRIC BUS BY DIFFERENT MANUFACTURERS

1

Cost per Metre

9m AC and 12m AC of same manufacturer (Tata Motors) cost per metre of 12m AC is 1.7 lakhs less than that of 9m AC.

2

Cost per kWh

On comparing the electric bus of different battery capacity i.e. 125kWh and 250 kWh, cost per kWh is 0.28 lakhs less that that of 125 kWh bus.

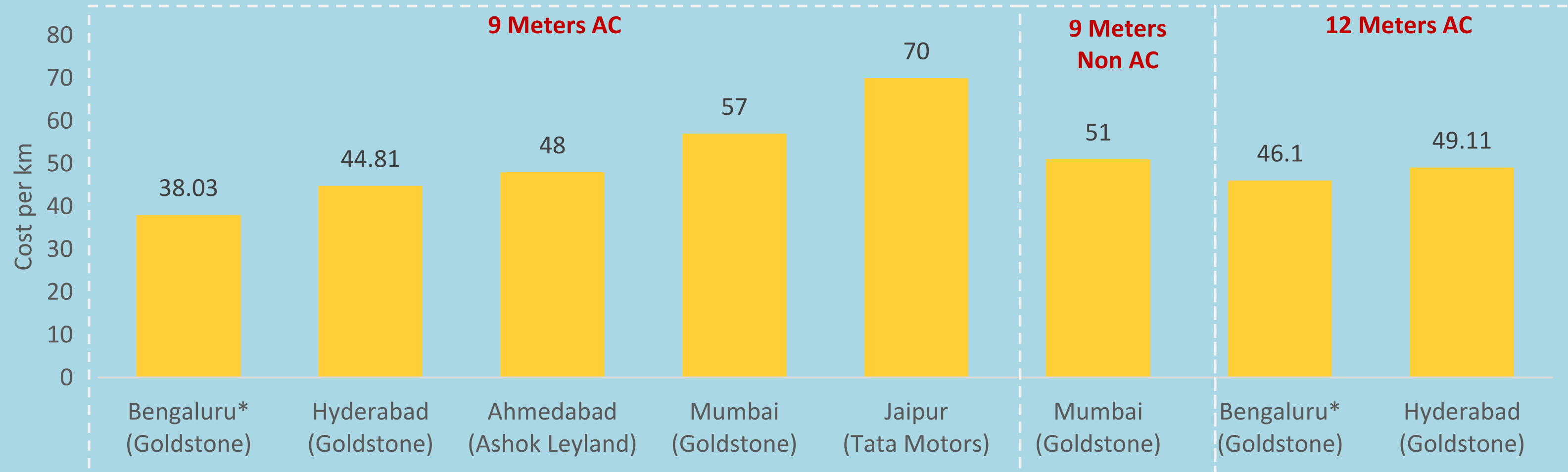
3

Recommendation

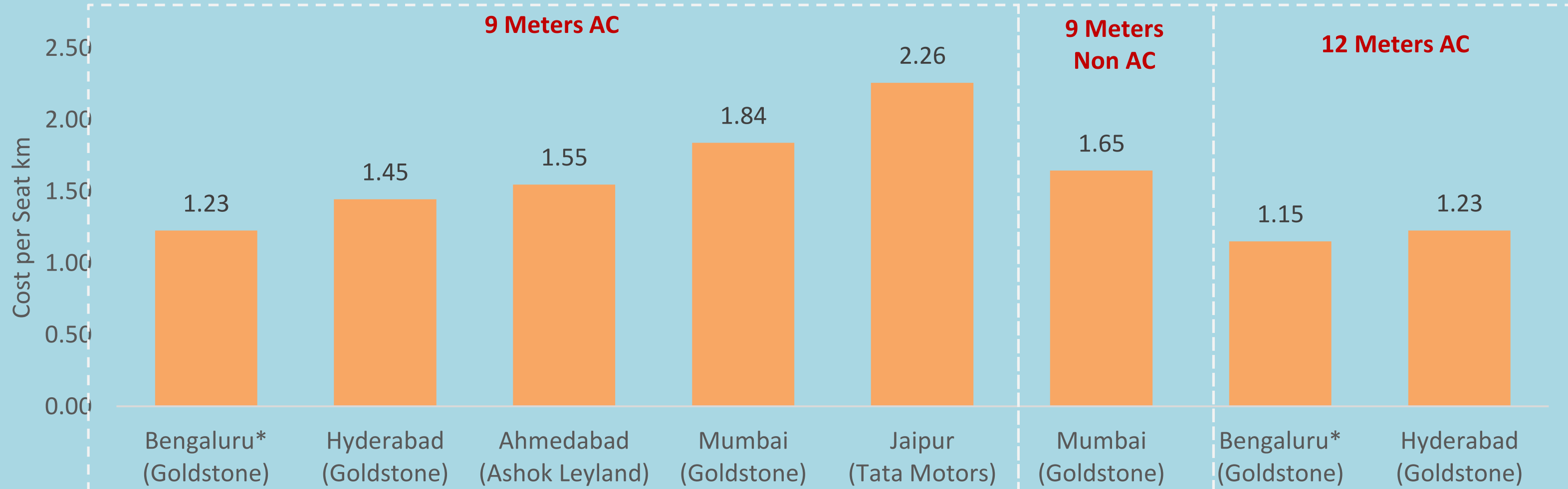
We can recommend to procure 12m electric bus rather than 9m electric bus in cities having enough RoW for 12m bus.

ELECTRIC BUS PROCUREMENT IN INDIAN CITIES

Bid Prices in Different Cities
₹ per km



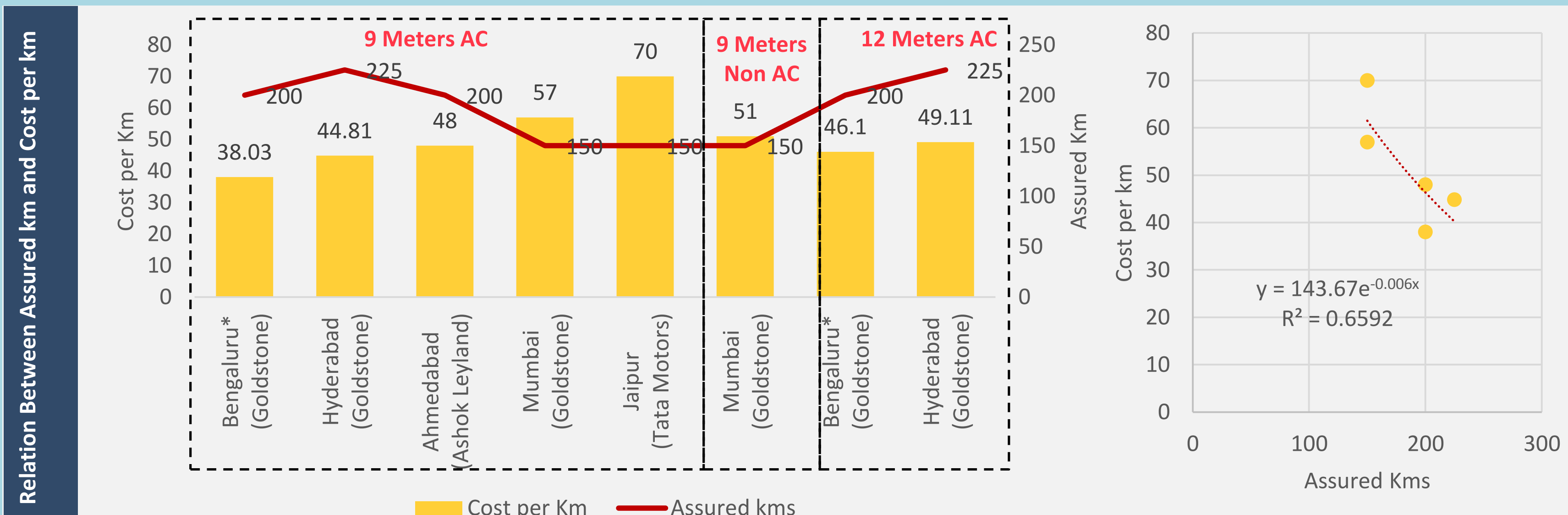
Bid Prices in Different Cities
₹ per Seat km



RELATION BETWEEN COST PER KM AND ITS DETERMINANTS

It is observed that there is a huge variation in tender conditions in different cities which results in variation in cost per km. under gross cost model

- Assured km
- Contract Period
- Battery Capacity
- Fleet Size

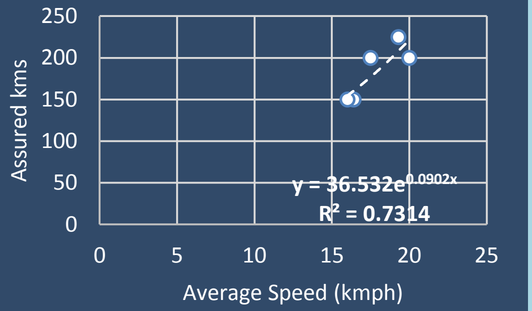


ANALYSIS OF ASSURED KM AND ITS DETERMINANTS

As mentioned in earlier section, the cost per km is a function of assured km to procure electric buses in GCC model. This section analyses how assured kms depends on the different attributes of the city, for which three parameters are taken into account.

Average Speed of the City

The average speeds of 5 cities i.e. Bengaluru, Hyderabad, Ahmedabad, Mumbai and Jaipur are regressed with the assured km of electric operations in each city. The relation between average speed and assured km is given in the figure below.



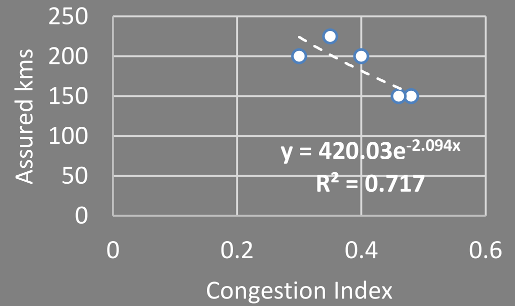
Congestion Index

Congestion Index = 1-(A/M)

Where,

M: Desirable average journey speed on major corridors of a city during peak hour, which is assumed as 30 KMPH, and

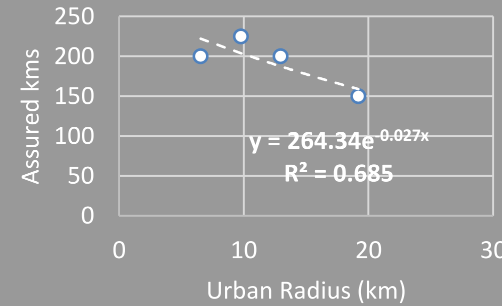
A: Average speed on major corridors of a city during peak hours



Urban Radius

Urban radius is accumulation of population or households by their distance from the city Centre. The point at which the slope of graph between population and distance from city centre drastically changes is considered as urban radius of the city.

$$Urban\ Radius = \frac{ATL - 2.9762}{0.6853}$$



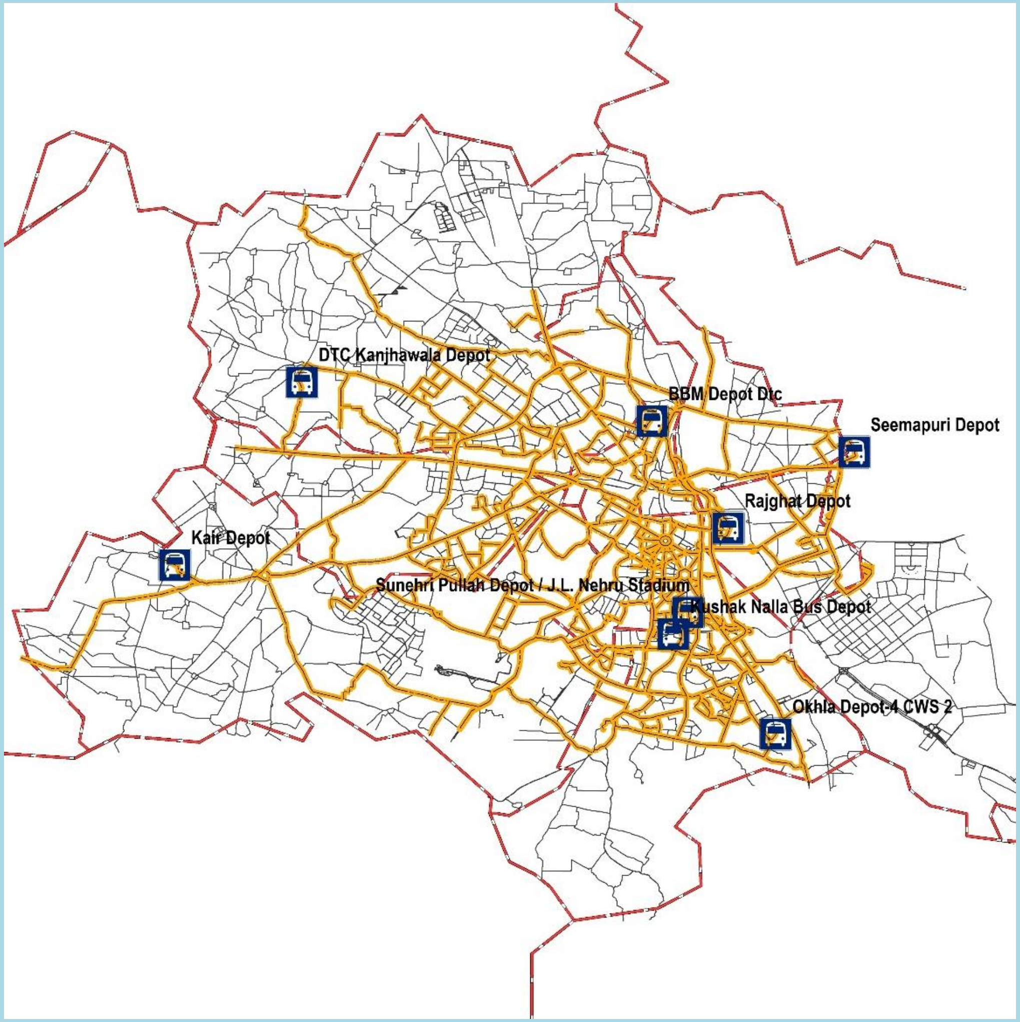
ANALYSIS OF ASSURED KM AND ITS DETERMINANTS

Comparison of Actual and Estimated Assured km in 5 Cities

City	Tender	Estimated		
		Average Speed	Congestion Index	Urban Radius
Bengaluru	200	185	183	179
Hyderabad	225	203	195	209
Ahmedabad	200	220	225	222
Mumbai	150	162	159	164
Jaipur	150	223	225	164

From the table, it is clear that urban radius of the city is most efficient to estimate the assured km, as the percentage of error between actual and estimated in existing 5 cities is least.

Profile of Case Study Area – Delhi



Area
1483 sq km

PCTR
1.55

Population (2018)
18.9 million

Average Trip Length
10.20 km

Population Density
9340 person/sq km

Total Fleet Size
5950 (4303+1647)

Profile of Case Study Area – Delhi

Dead Kms of Routes from Depots

Depots	Average of Dead kms	Sum of Number of Buses in operation
BBM Depot	15.7	126
Kair Depot	24.6	222
Kanjhawla Depot	22.3	153
Kushak Nallah Depot	12.6	352
Okhla Depot IV	15.7	148
Raj Ghat Depot	13.0	108
Seemapuri Depot	17.5	134
Sunehari Pulla Depot	14.9	191

Route	Avg Operational Km/Day	Avg Units Consumed (kWh)	Avg kWh/Km
473	194.77	181.86	0.88
TMS	203.47	183.11	0.93

- Govt. of NCT of Delhi has initiated a trial run of electric buses in order to understand the intricacies of operating these buses.

INFERENCE

- Kushak Nallah Depot have the least dead miles and highest number of buses in operations. So the routes originating from it should be given highest priority for electric bus operations
- Average energy consumption without AC is 0.88-0.9 kWh/km

Methodology for calculation of cost/km in Delhi

Regression between Cost/km and Assured km in present 5 cities

Y (Cost per km) = 143.67e^(-0.006*Assured kms)

Relate assured km with 3 parameters

Average Speed of the City (Wilbur Smith Report 2008 X Correction Factor)	Congestion Index of the City *(CI=1-(Moving Speed/Avg Speed)*	Urban Radius of the City UR=[(ATL-2.9762)/0.5027]

Calculate the assured km from the above parameters for Delhi

1.6376*Avg Speed^(1.638) 201 km	420.03* e^(-2.094*CI) 193 km	264.34* e^(0.027*UR) 191 km

Taking the assured as per urban radius = 191 km

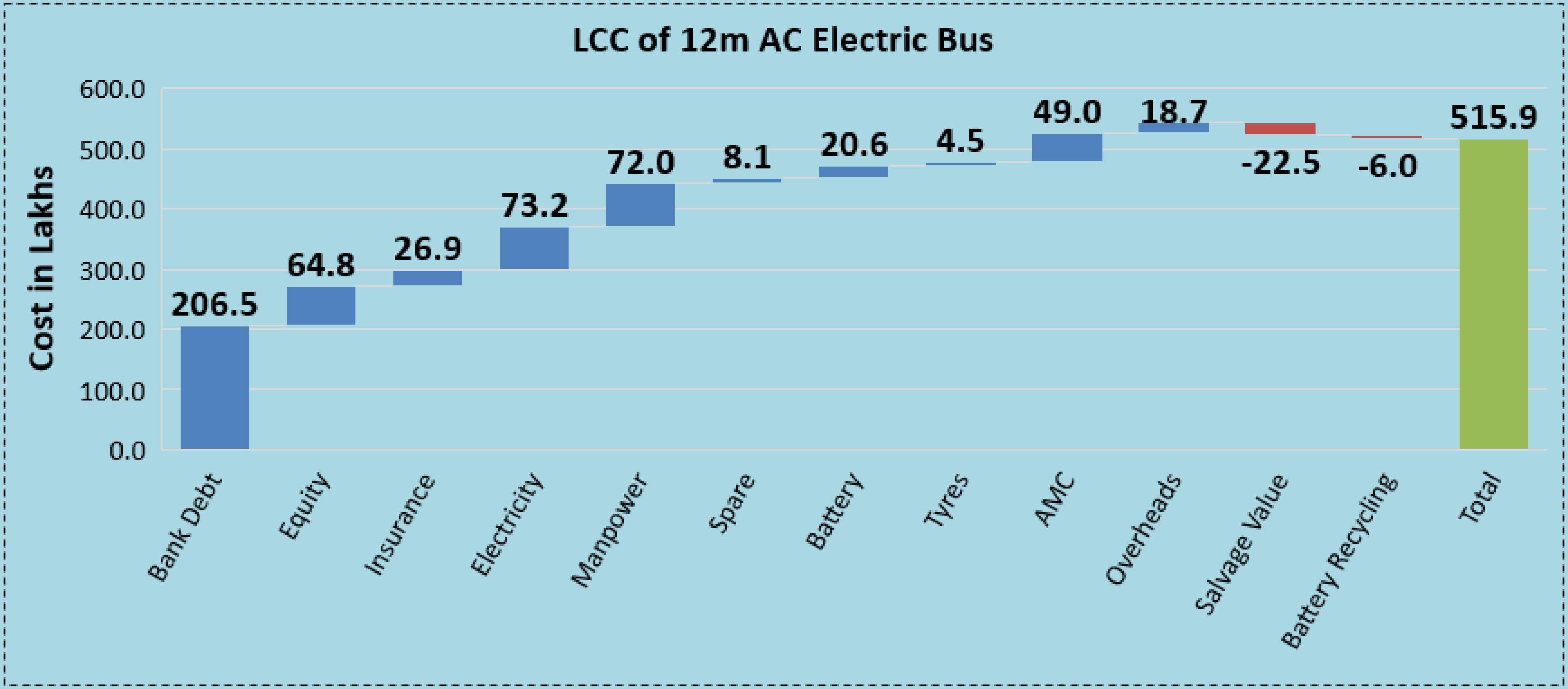
Cost per km (9m AC Electric Bus) = **₹48.92**

Ratio of AC Bus/Non Ac Bus **1. 11**	Ratio of 12m Bus/9m Bus **1.09**

Cost per km (9m Non AC E-Bus) = **₹44.64**
Cost per km (12m Non AC E-Bus) = **₹49.89**
Cost per km (12m AC E-Bus) = **₹54.68**

ALTERNATE MODELS FOR PROCUREMENT

GCC MODEL FOR PROCUREMENT OF ELECTRIC BUS (12M AC) IN DELHI



Under this procurement, the operator will start making profit after 4 years of operations

BATTERY LEASING MODEL FOR PROCUREMENT OF ELECTRIC BUS (12M AC) IN DELHI

Pay for the Bus, Lease the Battery

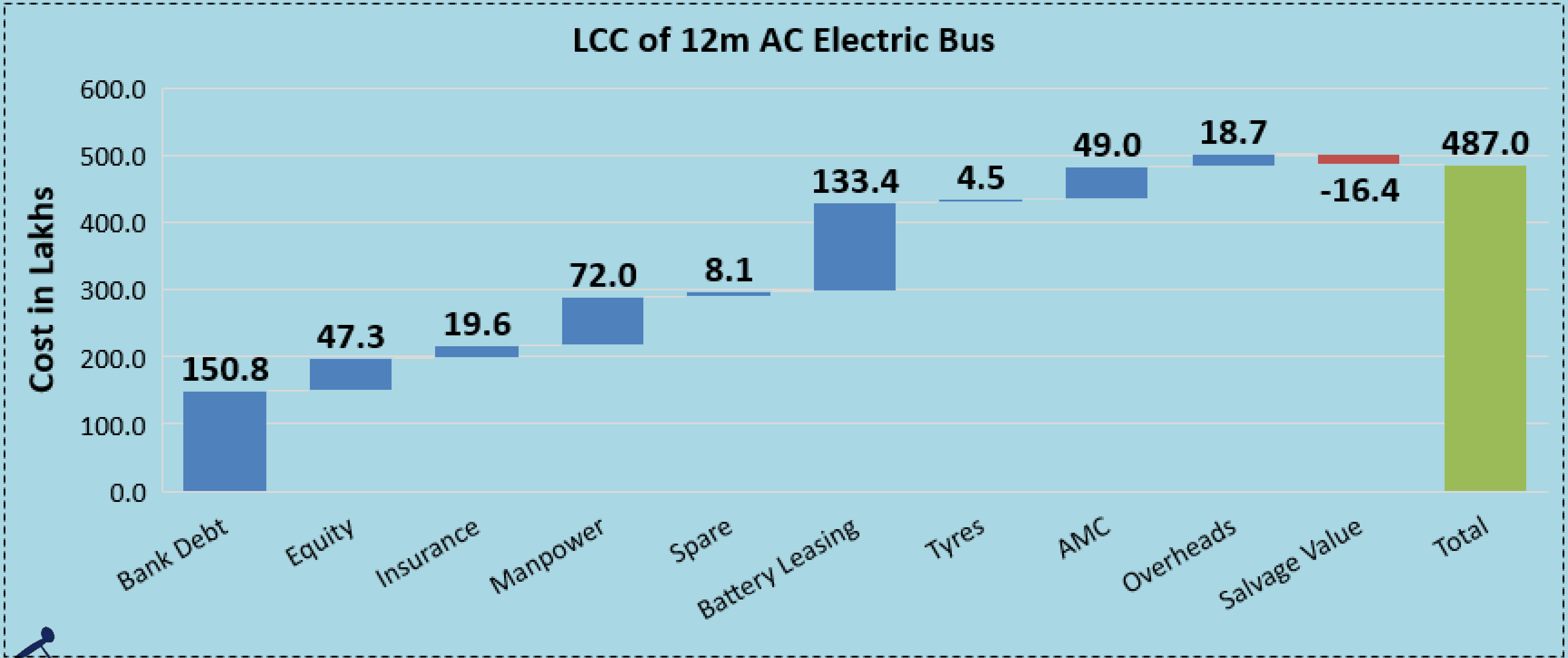
Battery Leasing Cost= Battery Cost + $\sum_{i=1}^{n}($ ***Recharging electricity Cost for given year i + Maintenance & Repair Cost for a given year i)***

Capacity of the Battery
250 kWh (Range 200km)

Cost of the Battery
INR 36,87,500(INR 14,750 kWH)

Maintenance & Repair
INR 12,54,870 (INR 1.5 per km)

Recharging Electricity
INR 51,12,433 (INR 6.1 per km)

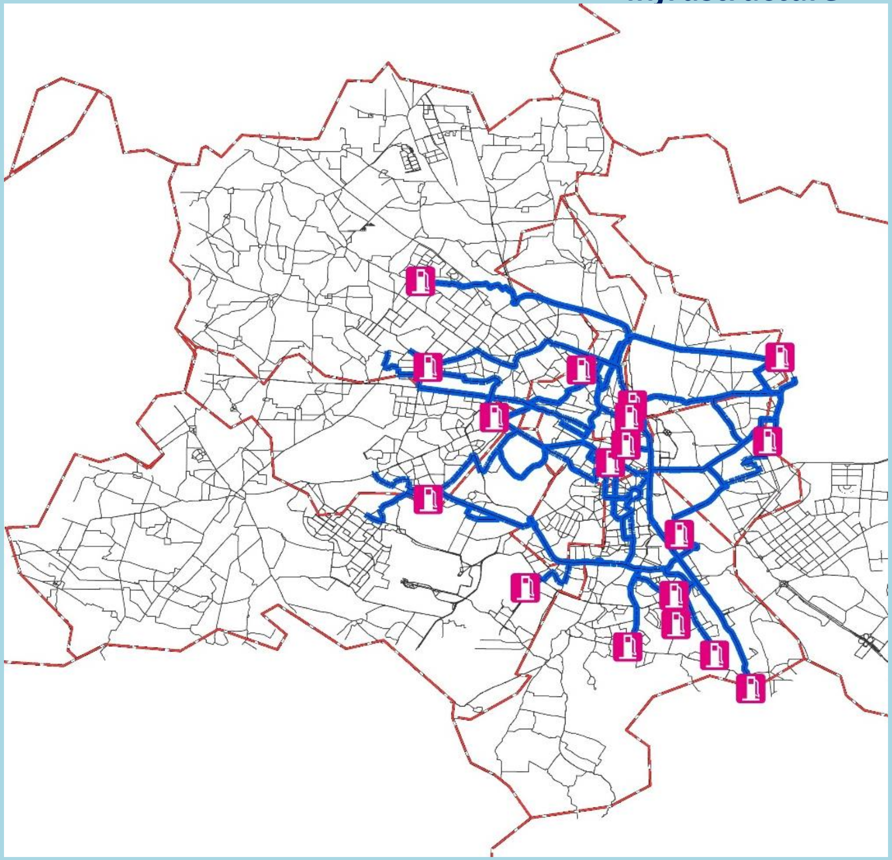


STRATEGIES

STRATEGY 1 – OPPORTUNITY CHARGING

Small Battery
Lower cost of Bus

Fast Charger
Higher cost of charging infrastructure



Assumptions	
Battery Capacity: **125kWh**	Charger Capacity: **320kWh**
Type of Charger: **CHAdeMO**	Time to Charge: **30-40 mins**

Total Buses in Operation
352

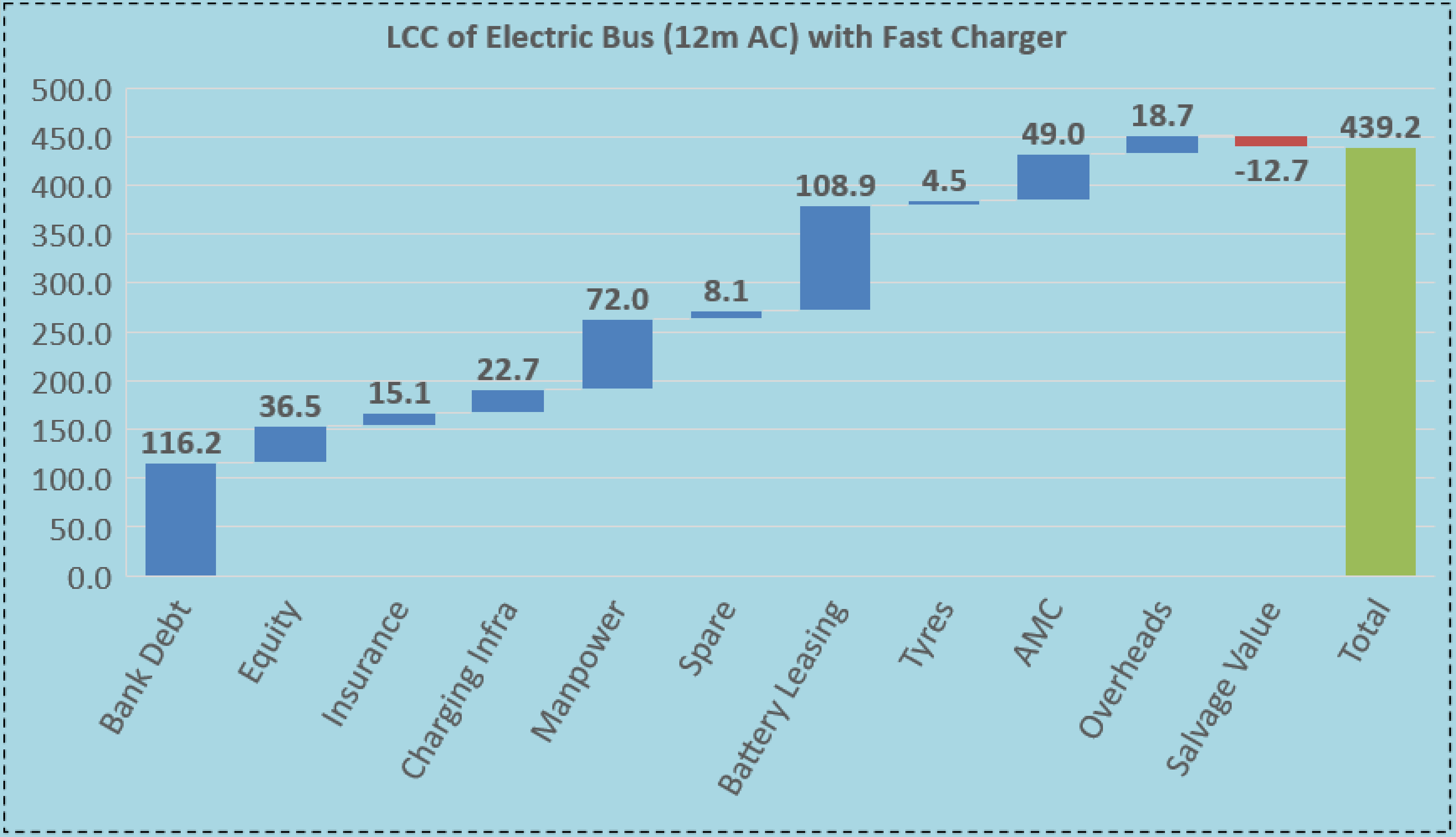
Chargers Required
66

Cost of Electrical Work per kWh
₹2,597

Cost of Civil Work per sqm
₹850

Delta Fast Charger (CHAdeMo) 320 kW	
Equipment Price	₹ 87,23,200
Installation Charge	₹ 96,000
Transportation Charge	₹ 76,800
GST (18%)	₹ 16,01,280
Electrical Work	₹ 8,24,320
Civil Work	₹ 40,800
TOTAL	**₹ 113,62,400.00**

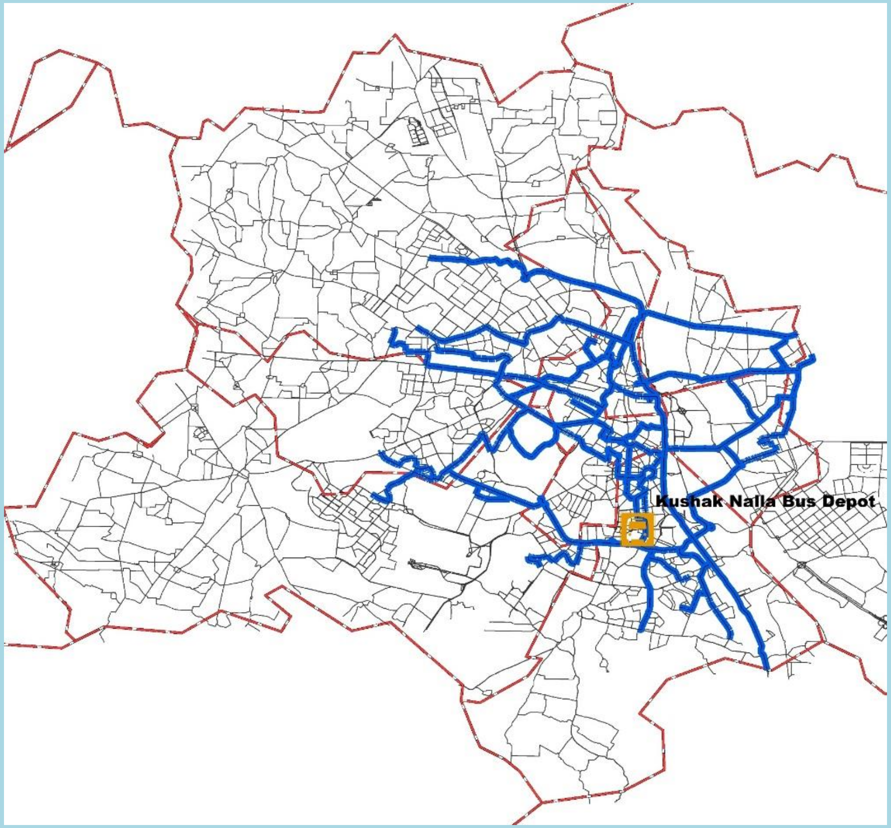
STRATEGY 1 – OPPORTUNITY CHARGING



STRATEGY 2 – DEPOT CHARGING

Large Battery
Higher cost of Bus

Slow Charger
Lower cost of charging infrastructure



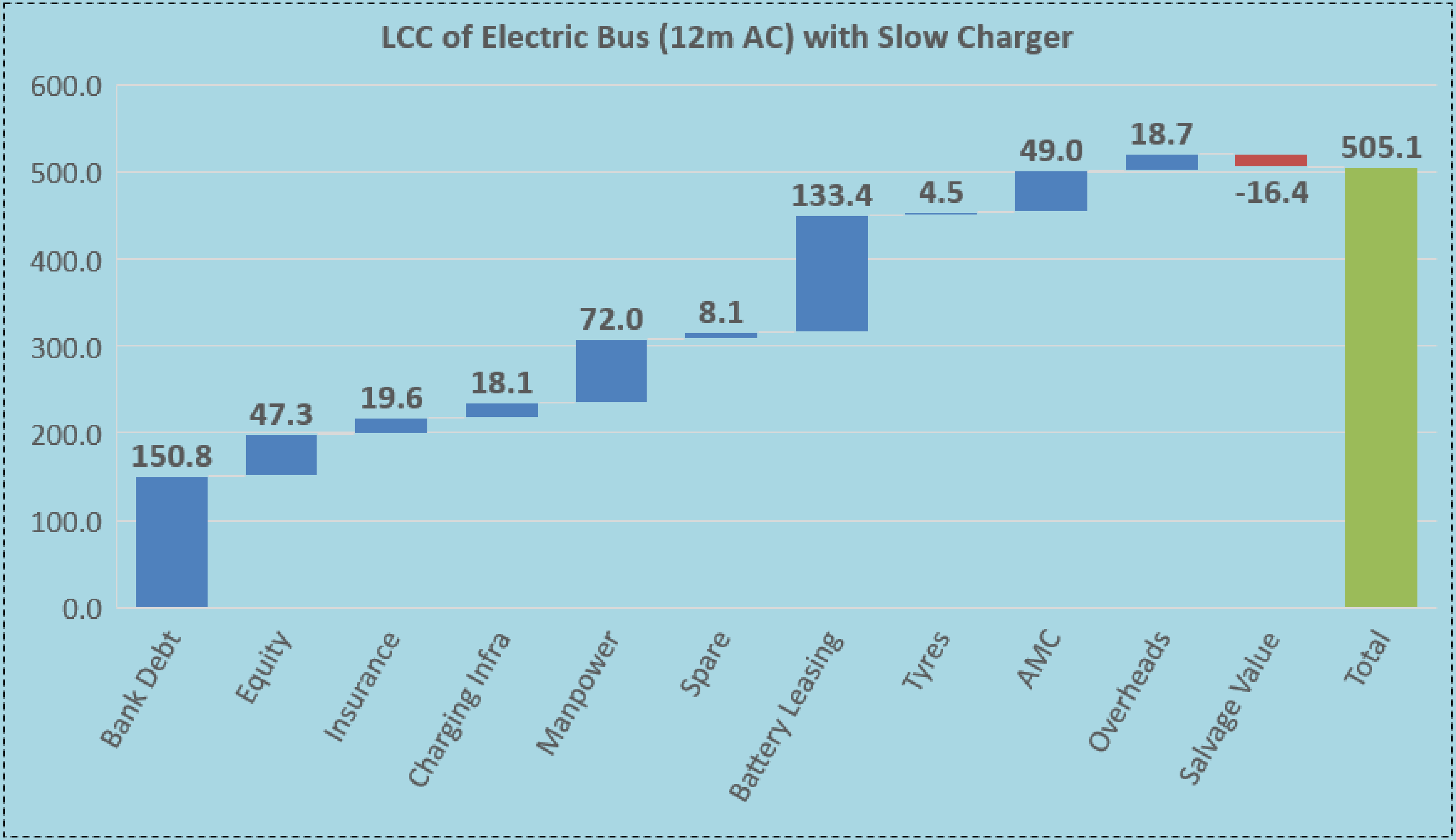
Assumptions	
Battery Capacity: **320kWh**	Charger Capacity: **50kWh**
Type of Charger: **Bharat Charger**	Time to Charge: **6-8 hrs**

Total Buses in Operation
352

Chargers Required
352

Delta Charger (CHAdeMO) 50kW	
Equipment Price	₹ 13,63,000
Installation Charge	₹ 15,000
Transportation Charge	₹ 12,000
GST (18%)	₹ 2,50,200
Electrical Work	₹ 1,28,800
Civil Work	₹ 40,800
TOTAL	**₹ 18,09,800.00**

STRATEGY 2 – DEPOT CHARGING



STRATEGY 3 – BATTERY SWAPPING

Small Battery
Lower cost of Bus

Battery
Swapping

Time to Swap
2.5 minutes

Cost/Swapper
₹26.78 lacs

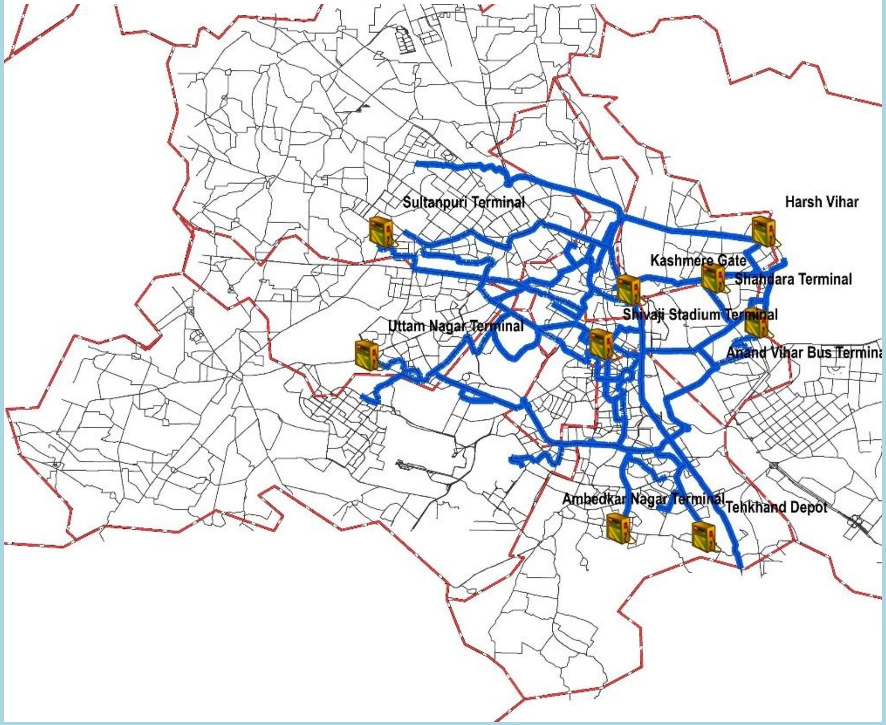
Area/swapper
200 sqm

No of swaps
24 buses/hr

Battery charge
30 min/battery

Civil Work
₹4,000/sqm

"Major end terminals are taken as optimal location for swapping station"



Location	Number of Buses in operation	Time to swap (mins)	No of Swappers	No of Fast Charger (320kW)
Ambedkar Nagar Terminal	20	50	1	3
Anand Vihar ISBT	77	193	3	10
Tehkhand Depot	13	33	1	2
Harsh Vihar	27	68	1	3
Kashmere Gate ISBT	59	148	2	7
Shahdara Terminal	27	68	1	3
Shivaji Stadum Terminal	23	58	1	3
Sultanpuri Terminal	48	120	2	6
Uttam Nagar Terminal	58	145	2	7
TOTAL	**352**		**14**	**44**

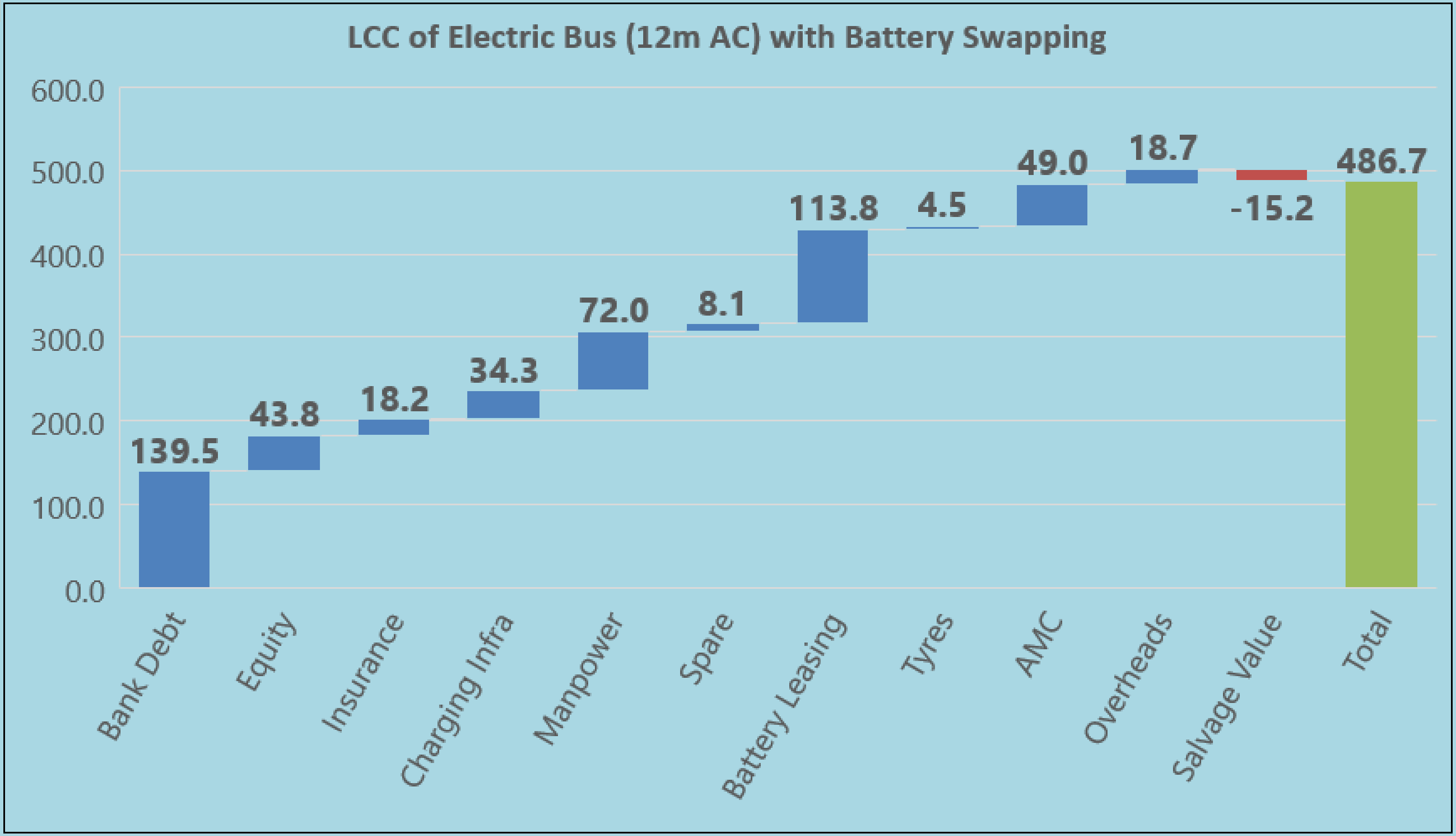
Total Infra Cost
₹ 4.87 Cr

Total Charger Cost
₹ 49.9 Cr

Total Battery Cost
₹ 65.7 Cr

= Total Cost
₹ 120.6 Cr
(For 352 buses)

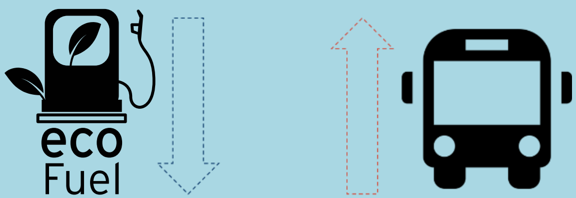
STRATEGY 3 – BATTERY SWAPPING



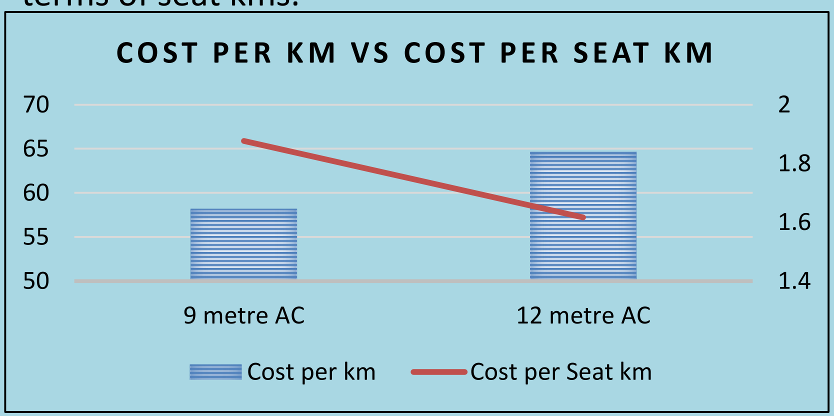
CONCLUSION

"Study points out that there is need to develop a robust model for electric bus operation"

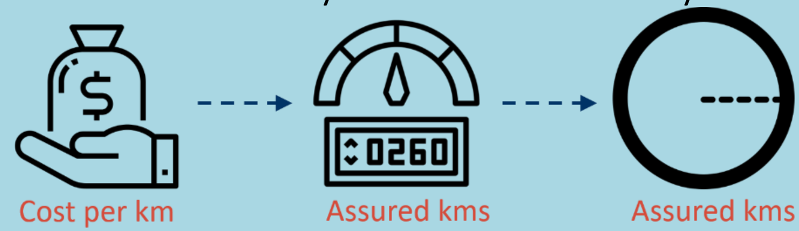
Life cycle cost of electric bus is less than CNG bus with zero emissions



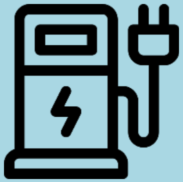
Electric buses of 12m are more cost efficient in terms of seat kms.



In bidding, cost per km is dependent on assured kms which is determined by urban radius of the city.

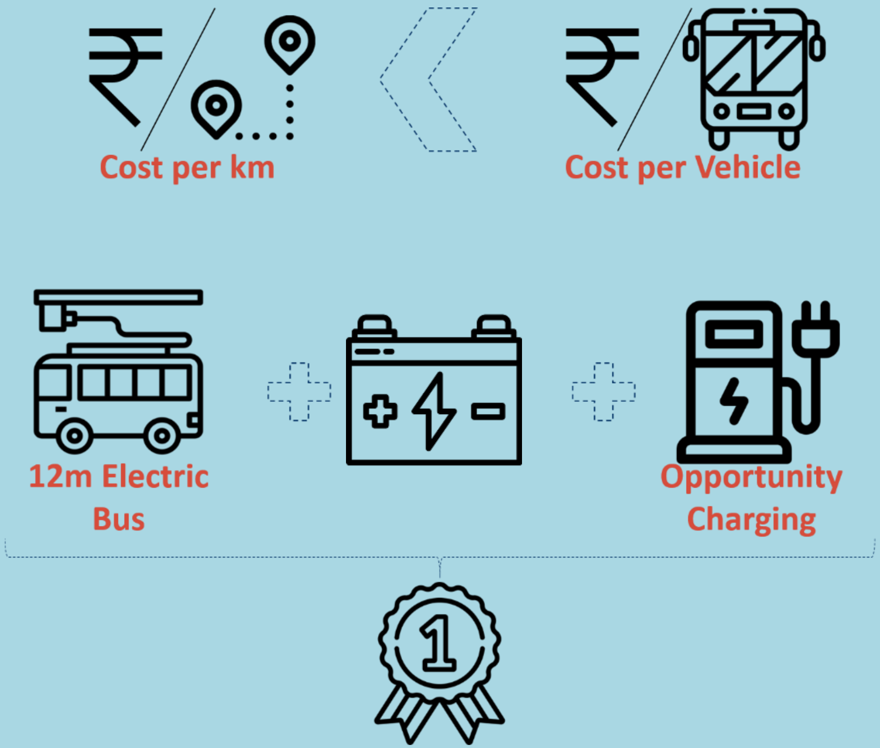


Electric buses should be procured on **BATTERY LEASE MODEL**



Opportunity charging operation is most cost effective for electric buses. Charger of high capacity should be use to charge the electric buses

RECOMMENDATIONS



- In urban areas electric buses should be procured on battery lease model as it decreases the upfront investments of the vehicle.
- Optimized charging and operations of electric buses, bus operators would be collaborated with charging infrastructure providers to furnish most of the routes with charging facilities
- There should be standardization of charger types.
- Utility funded installations

Thank You