LANDUSE PLANNING FOR ELECTRIC VEHICLE INFRASTRUCTURE

GARGI GHOSH
Sky Group, India

ABSTRACT

India is committed to the Paris Agreement by making efforts to reduce the emissions intensity of its GDP by 20–25% from its 2005 levels by 2020 and by 33–35% by 2030. As a part of this commitment, India intends to adopt 30% electric vehicles (EVs) in its vehicle population by 2030. In pursuant to the mission, the government has formulated the Electric Vehicle Policy, Model Building Guidelines and other related policies and guidelines. Various financial tools and incentives have also been declared. Large scale adoption of EVs would require provision of various infrastructures for the EV users. One of the major requirements is the availability of accessible charging infrastructure. Providing accessible charging infrastructure for EVs within the urban landscape would pose various locational, financial and technical challenges. Needless to say, there is a need for identifying spatial and landuse planning strategies to accommodate and sustainably plan for EV infrastructure. There has been a good initiative of work on locational models, plans, user perspective and business models for charging stations. However, works on landuse planning for charging infrastructure is still in its nascent stage. The aims of the paper are to (a) explore the necessity of deriving a landuse planning framework for EV charging infrastructure; and (b) to identify a replicable model for spatial planning for EV charging infrastructure for Indian cities. The paper reviews the various applicable guidelines for EV infrastructure and best practices, locational theories, zoning and building regulations and arrives at a framework for landuse planning for EV infrastructure. The case area for the study is Bangalore city.

Keywords: electric vehicles, charging infrastructure, India, Bangalore, landuse planning, AHP.

1 INTRODUCTION

India has committed to five key elements of the Climate Plan at the 26th session of the Conference of the Parties (COP26) to the United Nations Framework Convention on Climate Change (UNFCCC) in continuation with the Paris accord of 2015. The five key elements of the action plan are (i) reach 500GW non-fossil energy capacity by 2030; (ii) 50% of its energy requirements from renewable energy by 2030; (iii) reduction of total projected carbon emissions by one billion tonnes from now to 2030; (iv) reduction of the carbon intensity of the economy by 45% by 2030, over 2005 levels; and (v) achieving the target of net zero emissions by 2070 [1]. The government of India has taken multiple strategic policy initiatives in the energy and transport sector to steer the nation to the path of achieving the climate plan.

National Electric Mobility Mission Plan 2020 is one of the key pillars of the plan promoting electric vehicle (EV) adoption in the market. The mission plan is accompanied by several operational, finance and technical schemes and guidelines to expedite EV adoption. EV markets and user characteristics worldwide has shown that EV adoption requires transcending the challenges on EV charging infrastructure (EVCI). The EV market in India is at a nascent stage and EVCI has been sparsely developed. Standardised models and guidelines for development and operation of EVCI in the Indian context are lacking. This paper aims to (a) explore the necessity of deriving a landuse planning framework for EV charging infrastructure; and (b) to identify a replicable model for landuse planning for EV charging infrastructure for Indian cities.

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2 LITERATURE REVIEW

Road transport is the largest consumer of oil in India and the third largest sector in terms of CO_2 emission, amounting to 1.69 tonnes of CO_2 emission per capita in 2019 [2]. Hence India has taken a conscious decision to move from internal combustion engines to battery electric vehicles. Electric Vehicles (EV) were slow in uptake in the market. However with advancement in battery technology, the potential of EV penetration in the vehicle market is promising. Efficient energy storage and charging of EV batteries have been at the epicentre of discussion in the EV ecosystem. EV batteries chargers are of two types – slow chargers (for home charging) and fast chargers (for public places) [3]. It has been widely studied that availability of charging infrastructure is a major concern for adoption of electric vehicles [4]. Sustainable EV charging business models on the other hand require adequate market demand. Locational models are hence important to resolve the conflicting situation [5]. Norway has one of the largest EV fleet in the world. Studies from the Norwegian EV market show that with growing EV penetration demand large scale public charging infrastructure in addition to home based charging system. A well spread public charging network has also shown increased propensity to encourage complete shift to EV in the household [6].

Research on EV and related infrastructure has gained momentum in the last decade. In countries with high EV penetration, the coverage of research is widespread. Research is found in the five main areas, (a) Needs assessment and gaps; (b) energy and finance; (c) sital design standards; (d) user experience; and (e) locational models. In the Indian context literature is found in areas of grid integration, operational models and locational models. Literature with respect to landuse and EV charging infrastructure is scarce. For the purpose of this paper, literature on locational models at global scale has been studied along with papers on policies, guidelines and literature on EV available in Indian context

2.1 Locational models

Published literature portrays a large array of charging station locational models. Majority of this research are within the last decade. The studies are focused on either economic impacts or power grid impacts. Among studies considering economic aspects, research on locational models is primarily of two types, (a) theoretical models; and (b) empirical applications. Theoretical works have concentrated on deriving mathematical models to assess locations for EV infrastructure with simulated data whereas empirical models focus on real spaces with spatial characters often with georeferenced data and provide proof of concept for various mathematical locational models. EV charging infrastructure site selection is a multiple criteria decision making (MCDM) problem as it is determined by several factors often contradictory [7]. Literature shows that AHP and fuzzy AHP have been used to determine the weights of criteria. PROMETHEE method has been used with four main and seven sub-criteria in a case study in Beijing to derive geographical locations of EV charging sites [8]. In addition to mentioned MCDM methods, fuzzy TOPSIS method [9], PROMETHEE and ANP [10] approaches, fuzzy Delphi and GRA-VIKOR combination [11] have also been seen in research as methods to arrive at results via MCDM in various case studies conducted in Beijing. GIS is a prominent tool in studies that work with georeferenced data. GIS based MCDM [12]–[14] methods have also been used for optimal site selection in Ankara, Istanbul and Spain.

Various evaluations attributes are found in literature discussed above which is used for the MCDM process for deriving site suitability. The evaluation attributes are compiled under the following heads – traffic factors, economic factors, social factors and influencing factors and presented in Table 1.

Table 1: Evaluation attributes compiled from literature.

Environmental	Economic	Service capacity	Societal
Destruction level on vegetation and water	Construction cost	Traffic convenience	Attitude of local residents
Waste discharge	Annual operation and maintenance cost	Daily service capacity	Local government support
Air pollutant reduction	Investment payoff period	Car ownership	
Adverse impact due to sound, dust, etc.		Proximity to taxi stand	
Distance to water resources		Traffic density	
Distance to landslide risk		Proximity to interchange stations	
Slope		Road network	
Topography		Proximity to LRT stations	
		Distance between CS and user	
		Distance between CS and destination	

Reliable data is the key to achieving realistic outputs. Data used for the site selection studies are either statistical data availed from Census or travel data for EV and travel data of conventional fuel vehicles, surveys or simulation data. Statistical data is found to be useful in user-oriented models. Residential population, income, socio-economic statistics have been used for assessing demand density for EV charging stations. Travel data from GPS tracking of EV or conventional vehicles have been used for predicting driving tendency to analyse EV charging locations. Survey data with driving behaviour, origin and destination as well as temporal information has also been used for charging station locational analysis.

The available literature, however, does not look into EV charging infrastructure from the point of view of landuse planning policy or zoning regulations. Hence, suitability criteria focused on landuse zoning and analysis with landuse focused data sets are scarce in literature.

2.2 Indian EV infrastructure planning scenario

There are 285 million registered vehicles in India [15]. As of 2021, the share of EVs in the market is less than 1%. The government of India has targeted 30% EV penetration by 2030. To achieve that a sales penetration of 80% for two and three-wheelers, 50% for four wheelers, and 40% for buses by 2030 is required [16]. Several steps have been taken by the government for facilitating and encouraging the market. Financial scheme like FAME I and II for financial nudging of manufacturing, technical specifications for charging system, guidelines for charging infrastructure, amendments to Model Building byelaws, planning guidelines (URDPFI) and battery swapping policy have been published. A planning guideline of at least one charging station in a 3 km × 3 km grid is prescribed, one charging station per 25 km along highways is recommended while at a regional level one charging station in a grid of 10 km × 10 km is desired in designated industrial parks, SEZs and estates [17]. 20% of available parking space will be considered for EV parking and related charging infrastructure in residences, points of work and commercial places [18]. EV charging stations are permitted in central district, central sub district, district centres, community centres, residential and industrial landuse zone in urban areas, along National Highways, identified growth node villages and along major roads. Minimum sital area of 13.5 m × 5.5 m is recommended for charging stations whereas minimum area if 5.5 m × 2.75 m is recommended for battery swapping stations [19].

A review of the guidelines on EVCI in India reveals that EVCI is being perceived in the same framework as fuel stations. However, long charging time requirement mandates EVCI to be treated in a distinct manner. EV vehicle adoption is anticipated at a higher rate in urban areas compared to rural areas. Market reports predict higher EV adoption in 2-wheeler, 3-wheeler, intra-city buses and light goods vehicles based on the availability of charging infrastructure. While 2-wheeler and 3-wheeler category vehicles can be charged at home and city buses and goods vehicles can be charged at the parking lots, no such ready options exist for 4-wheelers making its adoption and in turn achievability of India's EV target arduous [20]. Hence city based EVCI will be a major requirement. In dense urban setting of Indian cities EVCI will have to compete will lack of vacant space and steep real estate price. This warrants a relook into the landuse planning and zoning regulations in cities.

3 METHODOLOGY

The present paper attempts to derive a landuse planning framework for EV charging infrastructure in two steps. Firstly suitable EV charging sites have been identified using multi criteria decision making methods and GIS using empirical data. The resultant output provides the basis of evaluating landuse policies with respect to sites suitable for EV infrastructure. Thereafter the present landuse zoning and regulation have been studied to derive an ideal landuse planning framework for EV charging infrastructure.

A list of decision criteria was compiled from those found in literature and presented in Table 1. Experts in the field of spatial planning, energy and GIS were interviewed to shortlist the critical criteria and assign prioritising scores as per Table 2. The priority scores were used for pairwise comparison in AHP. 10 sets of interview data were collected from this study. "Proximity to roads", "proximity to residential areas", "proximity to work centres and commercial centres", "proximity to interchanges" and "availability of open space" were the five criteria shortlisted for the present paper. "Proximity to road" represented accessibility and a higher accessibility was more suitable for locating EVCI. "Proximity to residential areas" and "proximity to work centres and commercial centres" represented demand, a higher proximity to residential areas represented higher demand for the EVCI which in turn represented higher financial feasibility. "Proximity to interchanges" like metro stations, bus stations represented demand. "Availability of open space" represented open space inside a property that could be used to set up charging stations.

Table 2: Rating used for prioritising criteria.

Sl	Preferences	Rating
1	Equally important	1
2	Moderately important	3
3	Strongly important	5
4	Very important	7
5	Extremely important	9

AHP was used for deriving the weights of the criteria, as shown in Table 3. Pair wise comparison of the five shortlisted criteria was conducted as per the relative scores from expert interview. Standardised matrix was derived and thereafter the criterion weights and consistency ratio (CR) analysis was performed to verify the accuracy of the AHP process. The sum total of the weights of the criteria is one. The CR of the AHP analysis was found to 0.034 which was well within the acceptable limits.

Table 3: Weights of criteria as derived from AHP.

Sl.	Criteria	Weights
1	Proximity to roads	0.167
2	Proximity to residential areas	0.167
3	Proximity to work centres and commercial centres	0.167
4	Proximity to interchanges	0.079
5	Availability of open space	0.42
		1.00

The data for GIS analysis corresponding to the above parameters were availed from public domain. The GIS layers pertaining to roads, landuse and interchange locations were suitably updated to reflect current situation in the study area. Open space data was available by deducting building footprint area from property area. Since the accuracy of this data directly affects the reliability of the study, great care was taken during the data transfer. Euclidean distance analysis was adopted for roads, work centres, residential and interchanges areas. Open space data was categorised into “less than 100 m^2” and “more than 100 m^2” categories and thereafter normalised. Weighted overlay analysis was performed on the normalised raster layers with the weights of the criteria obtained from AHP.

The study area is Bangalore city. Bangalore is the third largest metropolis in India after Mumbai and New Delhi. It has the second highest EV adoption rate in India at present. The city has a population of about 10 million. It can be considered as a representative urban area in the country.

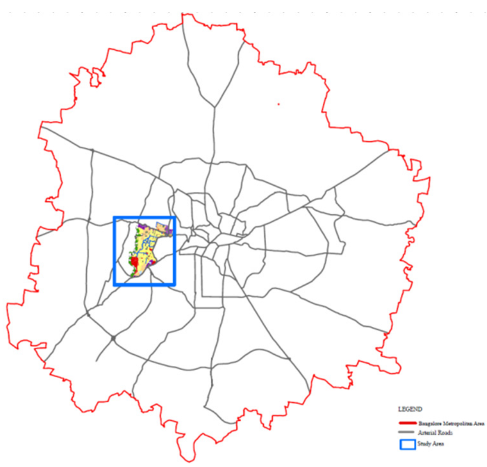


Figure 1: Location of study area in Bangalore. *(Source: Bangalore Revised Master Plan 2015.)*

A part of the city's western area measuring about 1.65 km^2 was taken up for the study, as shown in Fig. 1. The existing landuse zoning area is characterised by middle to upper middle class residential areas interspersed with neighbourhood level markets, zonal markets, well distributed healthcare and educational facilities, parks and government offices, as shown in Fig. 2. The area is connected to the rest of the city via road and metro rail. There are no major variations in slope, forest, water bodies or other protected areas. The urban fabric of the area is dense and representative of the urban fabric of the city.

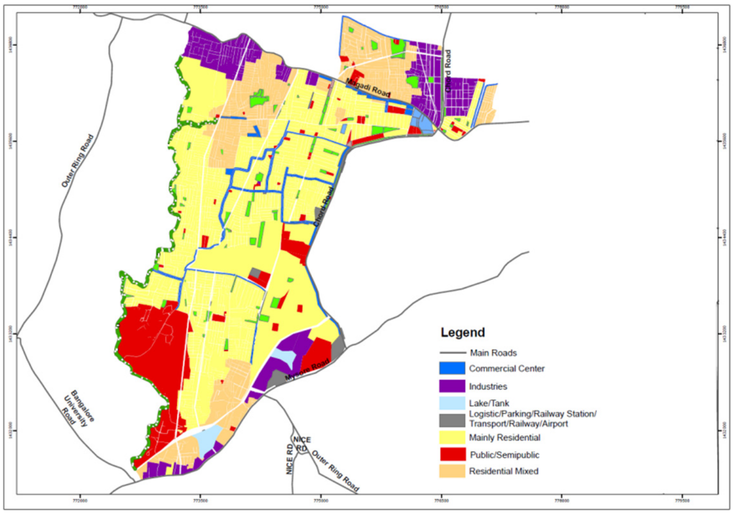


Figure 2: Landuse zoning in study area. *(Source: Bangalore Revised Master Plan 2015.)*

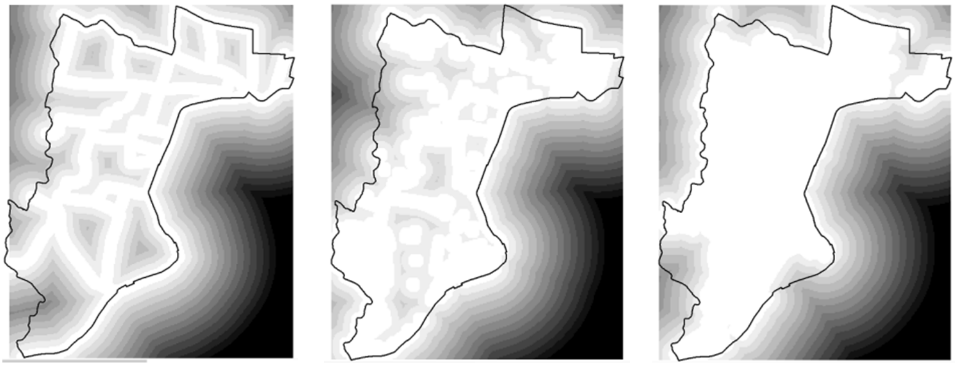
4 RESULTS

The weighted overlay analysis used the spatial layers of the five factors used for the multi criteria decision making model. The suitability output of the individual layers is shown in Fig. 3.

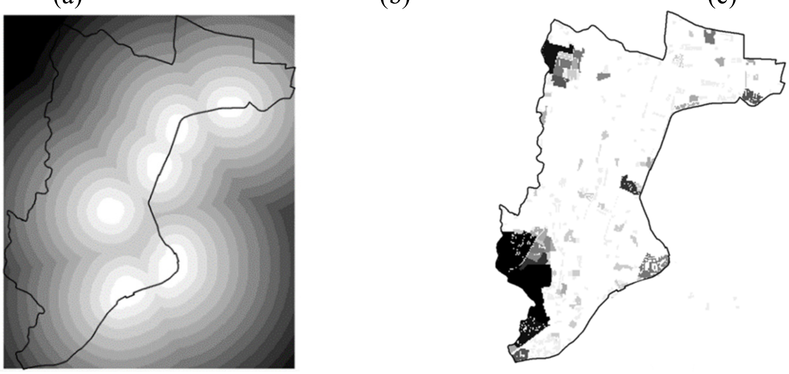
The weighted overlay analysis using the weights derived from AHP generated a graded suitability map of the study area, as shown in Fig. 4. The output was further reclassified to generated sites scoring 0.5 and above in the suitability score to generate "more suitable sites" for EVCI. The more suitable site locations were then studies with respect to their present zoning. It was revealed that the suitable site locations were at present zoned under parks, transportation use (bus depots, metro station premises) and public and semi-public use (hospitals, schools, government office premises) and industrial use zones. The suitable locations did not coincide with residential or commercial landuse.

5 LANDUSE PLANNING WITH RESPECT TO EV CHARGING INFRASTRUCTURE

EVCI is a relatively new concept in India with an introductory set of guidelines related to building bye laws as well as zoning. The URDPFI (urban and regional development plan formulation and implementation) guidelines serve as a model for urban planning published by the Ministry of Housing and Urban Development, government of India. The guideline has however no legal bearing upon the cities. Landuse zoning as well as development regulations

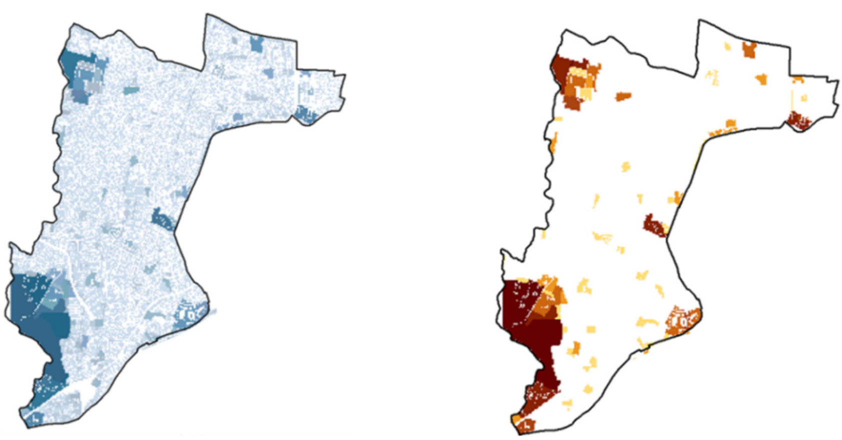


(a) (b) (c)



(d) (e)

Figure 3: GIS output of each criteria layer. (a) Proximity to major roads; (b) Proximity to work centres; (c) Proximity to residential areas; (d) Proximity to interchanges; and (d) Availability of vacant land.



(a) (b)

Figure 4: Suitable sites EV charging stations. (a) Suitability map; and (b) More suitable locations.

are set by the respective development authorities. In the case of Bangalore the Revised Master Plan (RMP) 2015 with its set of proposed landuse zoning maps and zoning regulations (development control regulations) form the legal regulatory framework for all landuse related activities in the city. The URDPFI amendment in response to EV policies classifies EVCI including charging stations, battery swapping stations as a “distribution service” at par with fuel stations. These are permitted in residential and industrial zones, along national highways, freight complexes, city centres and district centres. For the purpose of evaluating the zoning and development regulations, the URDPFI classification has been considered.

The zoning regulations of RMP 2015 do not recognise EVCI as a permissible use at present. However, if the URDPFI classification is to be considered, we find that EVCI is permitted as a main use in “commercial axes”, and as an ancillary use (permitted in 20% of site area) in “residential main”, “commercial business zones”, “public and semi-public” and “transportation zones” as seen in Table 4.

Table 4: Landuse zones and permissibility of EVCI.

Sl	Landuse category	Description	Permissibility of EVCI
1	Residential main	Area of mainly residential in use	Permitted as ancillary use
2	Residential mixed	Area of mixed residential and commercial use	Not permitted
3	Commercial central	Commercial areas in the core city mainly wholesale markets	Not permitted
4	Commercial business	Central business district	Permitted as ancillary use
5	Mutation corridor	One property deep areas along the radial arterial roads	Not permitted
6	Commercial axes	Commercial areas within residential zones	Permitted as main use
7	Industrial general	All industries except IT and ITES	Not permitted
8	Industrial hi-tech	IT and ITES industry	Not permitted
9	Public and semi public	Education, healthcare and government buildings	Permitted as ancillary use
10	Traffic and transportation	Premises of transport infrastructure – bus depot, metro station, parking lots	Permitted as ancillary use
11	Public utility	Premises of water supply, sewerage, electricity, power solid waste management infrastructure	Not permitted
12	Park and open space	Parks, playgrounds, stadiums, pool, libraries, cemeteries	Not permitted
13	Agricultural use	Agricultural areas with no developable zone	Not permitted
14	Unclassified	Defence establishments	Not permitted

5.1 Zoning of electric vehicle charging infrastructure

EVCI has been categorised similar to fuel stations at present. While fuel stations present very risk of life and property destruction [21] EVCI hazards from EVCI connected with smart grid and communication server has proven to be comparatively low [22]. Hence there is a need to distinguish EVCI from fuel stations. Fuel stations at their present grid density cater to the market demand. Charging station requirement will be much higher owing to the longer time requirement per vehicle. It calls for a necessity to recognise EVCI in terms of zoning so that large numbers of such structures can be integrated into urban landuse with due considerations of safety.

5.2 Permissibility of electric vehicle charging infrastructure in various landuse zones

The results of the site suitability analysis represent the feasible locations of setting EVCI for public use. As seen in the previous section, the feasible sites also coincided with parks and public and semi-public use and transportation zones. Parks are not considered feasible sites as they are not developable lands.

Public and semi-public areas are work centres and with exceptions to private schools and hospitals, are often located on government land. These premises tend to be large with low density development. The situation is similar is most of the Indian cities. Space availability and public ownership would provide lucrative market opportunity for use as EVCI for 2-wheelers as well as 4-wheelers. The zoning regulations at present does not permit EVCI in Public and semi-public lands. If considered similar to fuel stations, it is permitted as an ancillary use, i.e. up to 20% of the site area. However, based on the preceding discussions in the paper, it would be helpful to amend the regulations to ensure EVCI supply in the urban market.

Traffic and transportation zones are premised of railway stations, metro stations, bus depots and parking lots. These are located close to work centres or residential neighbourhoods as major transport infrastructure are planned to connect work/business centres to residential centres. These also have large premises and are almost always on government owned lands. These provide opportunity for setting up for charging stations for 4-wheelers as well as buses and goods vehicles where vehicles can be left for long hours overnight or during the day. The conditions would be similar in most Indian cities. The zoning regulations again do not recognise EVCI and if considered similar to fuel stations, is permitted as ancillary use only. It is imperative that the zoning permits EVCI on these zones as a main use to ensure market supply for public charging infrastructure.

Considering the approach of the URDPFI, EVCI should also be a permitted use in industrial and commercial zones.

6 LIMITATIONS OF THE STUDY

The study area selected for the study is a portion of the city. It is meant to be representative of the urban fabric of Bangalore while facilitating ease of data handling and ensuring realistic results. The data used for the study was also current and great care was used for data transfer to arrive at accurate results. However, study conducted at the city scale would add several infrastructure and landuse parameters to the study which may add different dimensions to the outputs. Such results with diverse and large datasets would add value to policy decisions for landuse and zoning. Hence study with city scale data would be more pertinent for study for policy decisions.

The present study focuses on parameters related to demand, accessibility and space availability based on expert's opinion and availability of reliable data. Environmental parameters may be added for the AHP and subsequent GIS analysis to receive environmentally sensitive outputs.

7 CONCLUSION

The paper presents a model of landuse planning with respect to EV charging infrastructure. The study area is a part of Bangalore city, which is representative of urban fabric of typical Indian cities. The study area hence is very relevant for the study considering high penetration of EVs expected in Indian cities. Accurate and updated datasets have been used for the analysis. The process used for analysis of data is well established in literature. The study is quantitative as well as empirical in nature and presents statistically relevant and realistic outputs.

Policy decisions related to landuse planning is often driven by land market trends. Integrating the transport network and travel pattern of the city with the urbanisation and land market trends is the key to sustainability. This study provides a unique methodology to arrive at landuse policy decisions related to EV charging infrastructure. Bangalore can be considered representative of general Indian city conditions and the outputs can be considered realistic for other Indian cities as well. The process is hence replicable for other cities and study areas.

Landuse policy sensitive to EV needs are highly recommended at this stage of the EV adoption curve in India. EV adoption rates can be increased only by increasing the EV charging infrastructure supply in the market. However, the urban land market would pose distinct challenges as highlighted in the paper. Hence innovative approaches are required to use the urban land to ensure the supply. The present paper uses on ground data to reveal suitable sites and thereafter proposes policy changes for utilisation of the same for EV charging infrastructure.

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