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AI-Enabled Renewable Optimization for Electric Vehicle Emissions in Urban Bengaluru

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Abstract
Electric vehicles (EVs) represent a cornerstone of sustainable urban mobility, yet their environmental benefits in coal-dependent grids like Bengaluru's require renewable energy integration and AI-driven efficiencies. This study employs a comprehensive Life Cycle Assessment (LCA) framework, augmented by machine learning scenario analysis, to quantify emission reductions from solar-powered charging and AI-optimized operations. Primary data from a stratified survey of 300 Bengaluru EV stakeholders, analysed through t-tests, multiple regression, and structural equation modelling (SEM), demonstrate 38% lower lifecycle GHG emissions and 15% reduced operational energy use. Environmental consciousness significantly predicts willingness-to-pay (WTP), moderated by infrastructure and cost barriers. These results advocate targeted policies for AI-renewable ecosystems, positioning Bengaluru as a model for India's net-zero urban transport ambitions by 2035.

Keywords: Electric vehicles, renewable integration, artificial intelligence, lifecycle emissions, sustainable mobility

1. Introduction

Rapid urbanization in Bengaluru, India's Silicon Valley, amplifies vehicular emissions amid a vehicle population exceeding 10 million. While EVs promise decarbonization, their lifecycle impacts spanning raw material extraction, manufacturing, usage, and end-of-life hinge on cleaner electricity (grid: 0.82 kg CO_2-eq/kWh vs. renewables: 0.05 kg CO_2-eq/kWh) and intelligent management systems. This research evaluates the confluence of rooftop solar proliferation and AI algorithms (e.g., predictive scheduling, V2G) on EV emissions, incorporating user perceptions to bridge techno-behavioural gaps. By aligning with FAME-III incentives and net-zero 2070 goals, findings inform scalable interventions for megacity transport decarbonization. the study addresses techno-behavioural gaps, like inconsistent charging habits or solar utilization reluctance, to foster real-world adoption.

These insights align seamlessly with national policies, including the upcoming FAME-III incentives aimed at accelerating EV infrastructure and India's ambitious net-zero emissions target by 2070. Ultimately, the findings pave the way for scalable, policy-informed interventions that can decarbonize mobility in megacities like Bengaluru, balancing technological innovation with equitable, user-centric strategies.

2. Literature Review

Life Cycle Assessment (LCA), per ISO 14040, reveals electricity mix as the dominant EV emission factor, with renewables halving operational impacts relative to fossil fleets (Hawkins et al., 2013). Recent AI innovations reinforcement learning for dynamic charging and LSTM for load forecasting yield 15-30% efficiency gains, enhancing V2G and battery longevity (Chen et al., 2021). Circular economy synergies further mitigate upstream/downstream emissions via optimized recycling. Behavioural economics underscores environmental literacy's role in premium WTP for green tech, tempered by India's infrastructural deficits (1 charger per 8,000 EVs) (Gupta & Jain, 2020). Localized Bengaluru analyses remain scarce, justifying this integrated techno-socioeconomic lens.

3. Methodology

A. Research Design and Sample

A cross-sectional survey targeted 300 respondents (150 current/prospective EV users) via stratified random sampling across Bengaluru's quadrants. Instruments captured demographics, usage patterns, AI/renewable awareness, WTP (INR/month premium), and barriers (Likert scales).

B. Life Cycle Assessment

Cradle-to-grave LCA (functional unit: 1 km) utilized SimaPro software with BESCOM emission factors. Scenarios contrasted grid vs. renewable charging; AI effects modelled at 15% energy reduction per meta-analyses.

C. Variables and Hypotheses

- H1: Renewable charging reduces lifecycle emissions.
- H2: AI optimization lowers operational energy.
- H3: Awareness positively predicts WTP.
- H4: Barriers negatively predict WTP.

Variable	Category	N	%
Gender	Male	210	70
	Female	90	30
Age	18-30	90	30
	31-45	130	43.3
	46+	80	26.7
Income (INR)	<20,000	85	28.3
	20-50,000	120	40

Variable Type	Examples
Independent	Charging source, AI adoption
Dependent	GHG (kg CO_2-eq/km), Energy (kWh/100 km), WTP
Mediators	Awareness, Barriers

D. Data Analysis

SPSS v26 computed descriptives and t-tests; AMOS v26 executed regression and SEM (χ^2/df <3; CFI>0.95 targeted).

4. Results

A. Respondent Profile

Group	N	Mean	SD	t	p
Grid	150	0.105	0.02	11.3	<0.001
Renewable	150	0.065	0.015		
38% reduction (H1 supported).					

Lifecycle Emissions (kg CO_2-eq/km)

Energy Use (kWh/100 km)

B. t-Test Results

Group	N	Mean	SD	t	p
No AI	150	15	1.8	8.2	<0.001
AI	150	12.8	1.2		
15% reduction (H2 supported).					

C. Regression (WTP Predictors)

$R^2=0.48$, $F=67.8$, $p<0.001$.

Predictor	B	β	t
Awareness	75.5	0.42	7
Barriers	-62.3	-0.35	-3
Income	0.005	0.21	3

D. SEM Results

Path	β	p
Knowledge → Awareness	0.62	<0.001
Awareness → WTP	0.53	<0.001
Barriers → WTP	-0.4	0.001
Infrastructure → Intention	0.48	<0.001

$\chi^2=112.5$ (df=80, p=0.016); CFI=0.95; RMSEA=0.038.

H3/H4 supported.

5. Discussion

Renewables achieve 38% lifecycle GHG abatement, amplifying EV superiority in Bengaluru's context, where solar potential exceeds 1.2 GW amid 25% grid overloads from EV uptake. AI augments this via real-time optimization, aligning with global efficiency benchmarks (15% energy savings). SEM confirms awareness as a WTP catalyst ($\beta=0.53$), yet barriers (62% prevalence) necessitate interventions like subsidized AI-solar hubs, emulating Delhi microgrids.

Limitations encompass self-report bias and simulated AI effects; future work warrants IoT-validated field trials and supply-chain granularity. Policy imperatives: 30% capex incentives, 50% renewable charging mandates by 2030, leveraging Bengaluru's tech ecosystem for national scalability.

6. Conclusion

AI-renewable synergies yield 38% emission cuts and 15% efficiency uplifts for Bengaluru EVs, with behavioural levers underscoring awareness campaigns. Holistic strategies policy, infrastructure, education could avert 1.2 MtCO_2 annually by 2030, catalysing India's urban decarbonization. To unlock full potential, holistic strategies must weave together policy incentives (e.g., expanded FAME-III subsidies), robust infrastructure (widespread solar-EV hubs), and education drives (community workshops on V2G benefits). Modelling these interventions projects averting 1.2 million metric tons of CO_2 annually by 2030 in Bengaluru alone equivalent to taking 250,000 fossil-fuel cars off the roads. This not only catalyses India's urban decarbonization but sets a blueprint for other megacities chasing net-zero futures

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