

**STUDY OF SELECT ISSUES IN THE MANAGEMENT OF ELECTRIC
VEHICLES CHARGING INFRASTRUCTURE IN INDIA**

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by

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Dedication

Dedicated to my parents.

CERTIFICATE

This is to certify that the thesis titled “Study of Select Issues in the Management of Electric Vehicles Charging Infrastructure in India”, being submitted by Ms. Ruchita to the Indian Institute of Technology Delhi, for the purpose of obtaining the Doctor of Philosophy (Ph.D.) degree, represents a genuine and original piece of research work conducted by her. I have supervised her work and she has met all the necessary criteria for submitting this thesis, adhering to the prescribed standards for obtaining a Ph.D. degree from our institution. The findings presented in this thesis have not been previously submitted, either in part or in full, to any other university or institution for the award of any degree or diploma.

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ABSTRACT

The surge in Electric Vehicle (EV) adoption has brought about a transformative shift in the conventional transportation sector. Historically reliant on fossil fuels, the traditional transportation system significantly contributes to global carbonization, emitting substantial greenhouse gases, particularly in India. Such emissions pose detrimental effects on both human health and the environment. In response, researchers and scientists have long been committed to reducing dependence on traditional fuels and promoting transportation systems with minimal atmospheric impact. Unlike traditional vehicles, EVs offer a cleaner alternative, mitigating the issue of air pollution.

Nevertheless, the widespread acceptance of EVs and the establishment of their charging infrastructure encounter numerous challenges. Whether fully or partially reliant on electrical energy, EVs face hurdles in achieving widespread adoption. While some research has been conducted on manufacturing suitable EVs, limited attention has been given to Electric Vehicle Charging Infrastructure (EVsCI), especially within the Indian context.

This research endeavors to identify and prioritize barriers hindering consumer adoption of EVs. It particularly focuses on managing issues related to EVsCI. Employing diverse methodologies, techniques, Stakeholders' Theory, and Transition Management Concepts, various frameworks and models have been developed to enhance the conditions of the EV industry and provide consumers with optimal infrastructure.

In Phase 1, a comprehensive framework for delivering efficient EVsCI in India was developed. This involved a PESTELI analysis to assess the current environment and potential changes, aiding in identifying challenges and opportunities within the EV industry. Subsequently, the

Soft System Methodology (SSM) was applied to formulate a Final Implementable Model and a Barrier Management Framework (BMF). The Final Implementable Model suggests the policies to be framed for EVsCI, whereas the Barrier Management Framework helps in providing a proper EVsCI.

Moving to Phase 2, barriers to EVsCI in India were identified through an extensive literature review, Systematic Literature Review (SLR), transition management concepts, stakeholder theory, and expert opinions. Employing the EFA methodology, the identified barriers were streamlined to sixteen. Here, 4 hidden constructs namely strategic, tactical, operational, and performance are obtained and a four-level transition management framework has been validated.

Phase 3 introduced the Total Interpretative Structural Modeling (TISM) methodology to establish an inter-relationship among these barriers. Unlike ISM, TISM addressed the "Why" alongside the "What" and "How." Subsequent MICMAC analysis revealed driving power and dependence among barriers.

In Phase 4, the Fuzzy Evidential Reasoning Algorithm (FERA) methodology was applied to prioritize barriers, creating an index for EV Charging Infrastructure in India.

Phase 5 incorporated a case study, utilizing literature reviews, stakeholder views, expert opinions, EV policies, and industry data. SAP-LAP analysis with the IRP approach proposed actions to enhance EV industry conditions and facilitate consumers with optimal EVsCI at charging stations. Actor vs. process and action vs. performance models were developed to aid policy formulation and implementation.

Key findings include the identification, categorization, and reduction of EVsCI barriers, development of models and frameworks for strategy formulation and improvement monitoring, categorization and ranking of barriers, and recommendations for government and manufacturers to enhance industry conditions and infrastructure for consumers.

The principal outcomes of this research can be outlined as follows:

1. Identification of Barriers: The study successfully pinpointed obstacles within the Electric Vehicle Charging Infrastructure (EVsCI).

2. Reduction and Categorization of Barriers: The identified barriers underwent a systematic reduction process and were organized into four distinct constructs.

3. Development of Models and Frameworks: Various models and frameworks were created to formulate strategies aimed at enhancing the state of EVsCI in India. These tools serve a dual purpose by not only guiding initial improvements but also facilitating ongoing monitoring and modification of strategies for continuous enhancement.

4. Categorization and Ranking of Barriers: The barriers identified were systematically categorized and ranked to provide a comprehensive understanding of their relative significance.

5. Recommendations for Improvement: The research yielded practical recommendations directed towards both governmental bodies and manufacturers. These recommendations aim to ameliorate industry conditions and establish proper infrastructure to meet the needs of consumers.

सार

इलेक्ट्रिक वाहन (EV) अपनाने में वृद्धि ने पारंपरिक परिवहन क्षेत्र में एक परिवर्तनकारी बदलाव लाया है। ऐतिहासिक रूप से जीवाश्म ईंधन पर निर्भर, पारंपरिक परिवहन प्रणाली वैश्विक कार्बनीकरण में महत्वपूर्ण योगदान देती है, विशेष रूप से भारत में पर्याप्त ग्रीनहाउस गैसों का उत्सर्जन करती है। इस तरह के उत्सर्जन मानव स्वास्थ्य और पर्यावरण दोनों पर हानिकारक प्रभाव डालते हैं। जवाब में, शोधकर्ता और वैज्ञानिक लंबे समय से पारंपरिक ईंधन पर निर्भरता को कम करने और न्यूनतम वायुमंडलीय प्रभाव के साथ परिवहन प्रणालियों को बढ़ावा देने के लिए प्रतिबद्ध हैं। पारंपरिक वाहनों के विपरीत, ईवीएस वायु प्रदूषण के मुद्दे को कम करते हुए एक क्लीनर विकल्प प्रदान करते हैं।

फिर भी, ईवीएस की व्यापक स्वीकृति और उनके चार्जिंग बुनियादी ढांचे की स्थापना कई चुनौतियों का सामना करती है। चाहे पूरी तरह से या आंशिक रूप से विद्युत ऊर्जा पर निर्भर हो, ईवीएस को व्यापक रूप से अपनाने में बाधाओं का सामना करना पड़ता है। जबकि उपयुक्त ईवी के निर्माण पर कुछ शोध किए गए हैं, विशेष रूप से भारतीय संदर्भ में इलेक्ट्रिक वाहन चार्जिंग इंफ्रास्ट्रक्चर (ईवीएससीआई) पर सीमित ध्यान दिया गया है।

यह शोध ईवीएस के उपभोक्ता को अपनाने में बाधा डालने वाली बाधाओं की पहचान करने और प्राथमिकता देने का प्रयास करता है। यह विशेष रूप से EVsCI से संबंधित मुद्दों के प्रबंधन पर केंद्रित है। ईवी उद्योग की स्थितियों को बढ़ाने और उपभोक्ताओं को इष्टतम बुनियादी ढांचा प्रदान करने के लिए विविध पद्धतियों, तकनीकों, हितधारकों के सिद्धांत और संक्रमण प्रबंधन अवधारणाओं को नियोजित करते हुए, विभिन्न ढांचे और मॉडल विकसित किए गए हैं।

चरण 1 में, भारत में कुशल EVsCI देने के लिए एक व्यापक ढांचा विकसित किया गया था। इसमें वर्तमान वातावरण और संभावित परिवर्तनों का आकलन करने के लिए एक PESTEL विश्लेषण शामिल था, जो

EV उद्योग के भीतर चुनौतियों और अवसरों की पहचान करने में सहायता करता है। इसके बाद, सॉफ्ट सिस्टम मेटाडोलॉजी (एसएसएम) को अंतिम कार्यान्वयन योग्य मॉडल और एक बैरियर मैनेजमेंट फ्रेमवर्क (बीएमएफ) तैयार करने के लिए लागू किया गया था। अंतिम कार्यान्वयन योग्य मॉडल EVsCI के लिए तैयार की जाने वाली नीतियों का सुझाव देता है, जबकि बैरियर मैनेजमेंट फ्रेमवर्क एक उचित EVsCI प्रदान करने में मदद करता है।

चरण 2 की ओर बढ़ते हुए, भारत में EVsCI की बाधाओं की पहचान एक व्यापक साहित्य समीक्षा, व्यवस्थित साहित्य समीक्षा (SLR), संक्रमण प्रबंधन अवधारणाओं, हितधारक सिद्धांत और विशेषज्ञ राय के माध्यम से की गई थी। ईएफए पद्धति को नियोजित करते हुए, पहचाने गए अवरोधों को सोलह तक सुव्यवस्थित किया गया था। यहां, 4 छिपे हुए निर्माण अर्थात् रणनीतिक, सामरिक, परिचालन और प्रदर्शन प्राप्त किए जाते हैं और चार-स्तरीय संक्रमण प्रबंधन ढांचे को मान्य किया गया है।

चरण 3 ने इन बाधाओं के बीच अंतर-संबंध स्थापित करने के लिए कुल व्याख्यात्मक संरचनात्मक मॉडलिंग (TISM) पद्धति की शुरुआत की। आईएसएम के विपरीत, टीआईएसएम ने "क्या" और "कैसे" के साथ "क्यों" को संबोधित किया। बाद में एमआईएमएसी विश्लेषण ने बाधाओं के बीच ड्राइविंग शक्ति और निर्भरता का खुलासा किया।

चरण 4 में, फ़ज़्ज़ी एविडेंशियल रीजनिंग एल्गोरिथम (FERA) पद्धति को बाधाओं को प्राथमिकता देने के लिए लागू किया गया था, जिससे भारत में EV चार्जिंग इन्फ्रास्ट्रक्चर के लिए एक सूचकांक बनाया गया।

चरण 5 में साहित्य समीक्षा, हितधारक विचारों, विशेषज्ञ राय, ईवी नीतियों और उद्योग डेटा का उपयोग करते हुए एक केस स्टडी शामिल थी। IRP दृष्टिकोण के साथ SAP-LAP विश्लेषण EV उद्योग की स्थितियों को बढ़ाने और चार्जिंग स्टेशनों पर इष्टतम EVsCI वाले उपभोक्ताओं को सुविधा प्रदान करने के लिए कार्रवाईयाँ प्रस्तावित की गयी। नीति निर्माण और कार्यान्वयन में सहायता के लिए अभिनेता बनाम प्रक्रिया और कार्रवाई बनाम प्रदर्शन मॉडल विकसित किए गए थे।

प्रमुख निष्कर्षों में ईवीएससीआई बाधाओं की पहचान, वर्गीकरण और कमी, रणनीति तैयार करने और सुधार की निगरानी, वर्गीकरण और बाधाओं की रैंकिंग, और उपभोक्ताओं के लिए उद्योग की स्थितियों और बुनियादी ढांचे को बढ़ाने के लिए सरकार और निर्माताओं के लिए सिफारिशें शामिल हैं।

इस शोध के प्रमुख परिणामों को निम्नानुसार रेखांकित किया जा सकता है:

1. बाधाओं की पहचान: अध्ययन ने इलेक्ट्रिक वाहन चार्जिंग इंफ्रास्ट्रक्चर (EVsCI) के भीतर बाधाओं को सफलतापूर्वक इंगित किया।
2. बाधाओं का न्यूनीकरण और वर्गीकरण: पहचाने गए अवरोधों को एक व्यवस्थित कमी प्रक्रिया से गुजरना पड़ा और उन्हें चार अलग-अलग निर्माणों में व्यवस्थित किया गया।
3. मॉडल और फ्रेमवर्क का विकास: भारत में ईवीएससीआई की स्थिति को बढ़ाने के उद्देश्य से रणनीति तैयार करने के लिए विभिन्न मॉडल और ढांचे बनाए गए थे। ये उपकरण न केवल प्रारंभिक सुधारों का मार्गदर्शन करके बल्कि निरंतर वृद्धि के लिए रणनीतियों की चल रही निगरानी और संशोधन की सुविधा प्रदान करके दोहरे उद्देश्य की पूर्ति करते हैं।
4. बाधाओं का वर्गीकरण और रैंकिंग: पहचान की गई बाधाओं को व्यवस्थित रूप से वर्गीकृत किया गया था और उनके सापेक्ष महत्व की व्यापक समझ प्रदान करने के लिए रैंक किया गया था।
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List of Abbreviations

3PL	Third-Party Logistics
APBs	Alternatively Powered Busses
AVs	Automated Vehicles
BEV	Battery Electric Vehicles
BMF	Barrier Management Framework
CAGR	Compound Annual Growth Rate
CEA	Central Electricity Authority
CEF	Connecting Europe Facility
CI	Consistency Index
CR	Consistency Ratio
CSCT	Chemical Supply Chain Transportation
DISCOMs	Distribution Companies
DP	Dynamic Program
DS	Dempster-Shaffer
EFA	Exploratory Factor Analysis
ERA	Evidential Reasoning Algorithm
ERP	Enterprise Resource Planning
EUT	Expected Utility Theory
EVs	Electric Vehicles
EVsCI	Electric Vehicles Charging Infrastructure
FAHP	Fuzzy Analytic Hierarchy Process
FAME	Faster Adoption and Manufacture of Hybrid and Electric Vehicles
FERA	Fuzzy Evidential Reasoning Algorithm
FST	Fuzzy Set Theory
ICE	Internal Combustion Engines
ICEVs	Internal Combustion Engine Vehicles
IEA	International Energy Agency's
IoT	Internet of Things

IRP	Interpretive Ranking Process
ISM	Interpretative Structural Modelling
ITI	Integrated Transportation Inventory
ITS	Intelligent Transportation System
IVHS	Intelligent Vehicle Highway System
KMO	Keyser-Mayer-Olkin
MICMAC	Matriced' Impacts Croises Multiplication Applique' and Classment
MILP	Mixed Integer Linear Programming
OR	Operational Research
PCI	Public Charging Infrastructure
PESTELI	Political, Economic, Social, Technological, Environmental, Legal, and Industrial
PEVs	Plug-In Electric Vehicles
PHEVs	Plug-In Hybrid Electric Vehicles
PMP	Phased Manufacturing Program
RI	Random Index
RITA	Research and Innovative Technology Administration
RO	Research Objectives
SAMARTH	Smart and Advanced Manufacturing and Rapid Transformation Hub
SAP-LAP	Situation, Actor, Process-Learning, Actions, and Performance
SCM	Supply Chain Management
SLR	Systematic Literature Review
SMEV	Society of Manufacturers of Electric Vehicles
SOH	State of Health
SSM	Soft system methodology
STS	Smart Transportation System
TFN	Triangular Fuzzy Number
TISM	Total Interpretative Structural Modelling
TMS	Transportation Management System
WOP	Willingness-To-Pay