MSc Programme in Urban Management and Development

Rotterdam, the Netherlands

August 2024

Decoding Regional EV Growth in India

A Fuzzy Set Qualitative Comparative Analysis of Supply and Demand Conditions

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- Governance and Economics of Cities

Report number: 1872

UMD2023-24

IHS
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Summary

As a global response to moderate carbon emissions and dependence on fossil fuels, sustainable mobility is spearheading the transition from ICEVs to EVs. The evolving EV landscape in India can be attributed to the evolving industry and consumer preferences. However, this EV growth varies significantly across the states due to varying regional policies, infrastructural provisions, and socio-economic characteristics. This variability despite similar national policies is the key problem addressed in this thesis, suggesting the crucial role of the interplay of policies with local factors. While previous studies have focused on national-level policies or the role of individual factors in pushing EV uptake, this study emphasizes the set-theoretic nature of policies. Therefore, taking forth a configurational approach, this study seeks to identify the different solution pathways that lead to high EV adoption. By analyzing the demand and supply-side conditions in 26 Indian States using Fuzzy-set Qualitative Comparative Analysis (Fs/QCA), the exploratory study uses secondary data to identify the state-level policy mixes and regional assets that foster EV growth. The findings reveal multiple pathways that lead to EV adoption by consumers and industries. The demand-side analysis indicates that the conjunction of financial incentives, non-financial incentives aimed at consumers, and a network of public charging stations is sufficient for EV adoption. Alternatively, in regions without enough incentives or concessions, EV adoption is driven by an individual's economic affluence and user comfort offered by charging infrastructure. The supply-side analysis reveals that in states with an established EV industry, either financial incentives and R&D support or non-financial incentives aimed at improving infrastructure and manufacturing are sufficient for EV deployment. In economically constrained states, without non-financial incentives, financial incentives encouraging manufacturing, research, and infrastructural development play an important role in increasing EV deployment. It was observed that most southern states with existing EV industries spearhead this transition by strengthening the supply or innovation side whereas, affluent states with tourism industries and public charging networks focus on the demand or consumer side. The results validate the configurational approach and policy mixes, highlighting that a combination of mutually reinforcing policies, which are tailored to the local context leads to favorable results.

Keywords

Electric vehicles, policies, regional assets, QCA, demand and supply

Acknowledgments

As my academic journey at IHS reaches its final calibration, I extend my gratitude to the necessary and sufficient conditions that have helped me to complete this thesis.

I thank my thesis supervisor Dr. Sofia Pagliarin for her invaluable guidance throughout this study, and her insightful comments significantly benefited the report. Most importantly, her patience in decoding my rather fuzzy ideas has been instrumental in my being able to explore and reach the final solution pathway.

I would also like to thank my fellow UMD students for being the perfect intermediate solution by sharing laughs, thesis struggles, and constructive feedback on my work. I extend my thanks to my family and friends back home for supporting and encouraging me throughout this period by at least pretending to understand what I am trying to do.

Special thanks to the DIGEC group for laying the foundation with diverse perspectives and discussions that have significantly shaped my understanding and the research process.

Finally to Ragin and all researchers and academicians whose work built the base of this study. I can only hope that the findings of this study can contribute to the existing knowledge and fill at least a few logical reminders.

The journey of writing this thesis has been filled with excitement, learning, and a fair share of caffeine-fuelled days. This thesis is an outcome of a combination of conditions and I am grateful to everyone who was a part of this journey.

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Abbreviations

Abbreviation	Full form
IHS	Institute for Housing and Urban Development Studies
EV	Electric Vehicle
PCS	Public Charging Stations
BEV	Battery electric vehicle
HEV	Hybrid electric vehicle
PHEV	Plug-in hybrid electric vehicle
IPCC	Intergovernmental Panel on Climate Change
FI	Financial incentives
NFI	Non-financial incentives
GDP	Gross Domestic Product
QCA	Qualitative Comparative Analysis
Fs/QCA	Fuzzy Set Qualitative Comparative Analysis
ICEV	Internal Combustion Engine Vehicle
GST	Goods and Service Tax

1. Introduction

"Alarming pollution levels and increasing fuel costs have necessitated the adoption of electric vehicles. While the government is making efforts both in terms of policy push and infrastructure, efforts should be made by individuals as well as enterprises to embrace sustainable mobility."

- Samarth Kholkar, Sep 2022 (Chandak, 2022, para. 6)

1.1. Background

The global climate has been observed to be drastically changing over the last ten years as a result of the sharp rise in greenhouse gas emissions (Yasmin et al., 2022). In attempts to counter these climate extremes, governments work towards reconciling urban development, climate protection, and energy security. Road transport has been a major contributor to these emissions, which shifts the focus towards transport decarbonization. Approximately 28% of the world's energy demand, 24% of carbon dioxide emissions that are energy-related, and 65% of the oil demand are generated by the transportation sector, of which 77% is emitted by road transportation, specifically passenger traffic (Zimm, 2021). By 2050, these emissions are expected to have doubled due to expected growth in the demand for transport energy, particularly in emerging and developing economies where demand for both individual and general mobility is rising (Zimm, 2021). This has made sustainability a core theme of urban mobility today, pushing for a paradigm shift from Internal Combustion Engine Vehicles (ICEVs) for a sustainable future. Operating at a level that is competitive with ICEVs and producing zero on-road emissions, electric vehicles (EVs) are positioned to play a crucial role in this shift (Dominković et al., 2018).

To reach the national net zero carbon emission targets by 2070 while simultaneously meeting the increasing demand for private mobility, EVs present a viable solution. Over the past decade, a higher number of EV models have become available, new initiatives for battery technology were launched, and diverse EV support policies were instituted in key markets (International Energy Agency, 2021). These dynamics drive the EV transition while also determining the direction of growth of EVs. More than 20 countries, including emerging economies, have goals for a full phase-out of ICEVs in the following 20-30 years. Therefore, plans, and policies to restrict and phase out the use of ICEVs are also gaining momentum (Goswamy et al., 2023) alongside those encouraging the use of EVs.

"*Electric vehicles come in various forms such as battery electric vehicles (BEVs), plug-in hybrid electric vehicles (PHEVs), hybrid electric vehicles (HEVs), and autonomous vehicles*" (Alanazi, 2023). BEVs are powered solely by on-board batteries, which are charged through outlets or charging stations (S. Singh et al., 2022). PHEVs are powered by batteries and petrol or diesel engines which take when it cannot run on electric power (Alanazi, 2023). HEVs are vehicles with both electric motors and petrol engines that take over in high-speed situations. These vehicles use regenerative braking and do not require plugging in to recharge (Alanazi, 2023). Although a few countries also observe a trend where PHEVs are becoming the dominant EV option, BEVs are the most common option, accounting for nearly 64% of the global EV fleet (Chen et al., 2020).

Electrification of short-distance vehicles has been identified by the Intergovernmental Panel on Climate Change (IPCC) to be an instrumental tool in reducing emissions (Rao Ghorpade et al., n.d.). Europe, China, and the US are the major EV markets today and have all used policies to kickstart EV adoption (Connelly, 2024). Especially in the early years of EV introduction, policies have been instrumental in electrification. Historically, policies have played a vital role in spearheading transitions. Technological improvements in the automotive industry have also been associated with policies either through safety regulations or guidelines to meet environmental mandates. It is also noteworthy that different countries approach policies differently ranging from supply to demand side policies depending on unique contexts. Norway and California have emerged as frontrunners in EV deployment. These jurisdictions utilized their unique pre-existing political, natural, and economic assets to synergize political and industrial dynamics to scale up EV adoption. Norway's policies set the foundation for developing a consumer market. The highly developed nation with its sufficient funds focuses on demand-side incentives to make EVs more attractive by reducing their purchase costs. The lack of an incumbent automobile and manufacturing industry could explain the failed attempts to build domestic EV manufacturing which forced a shift towards demand-side policies. On the other hand, California's policies are led by an economic and political response to air pollution by taking advantage of the state's technical capacity in manufacturing. Therefore, the policies are innovation or supply-side focused which pushes the established automotive industry to leverage their resources and spearhead the EV market (Lemphers et al., 2022). Policies are also used as catalysts to develop supply chains to ramp up domestic production and focus on manufacturing and not just deployment (International Energy Agency, 2023a).

1.2. Research Problem – Where India Stands

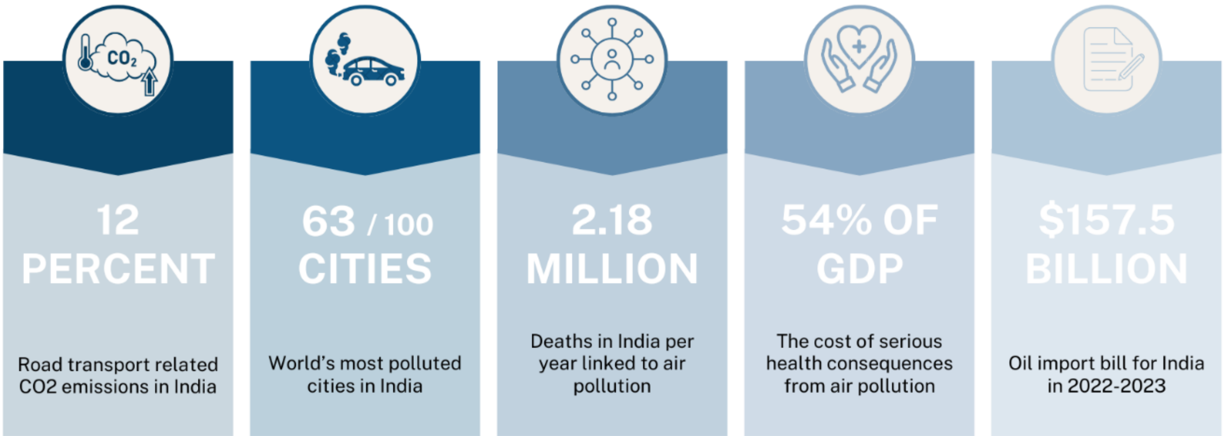
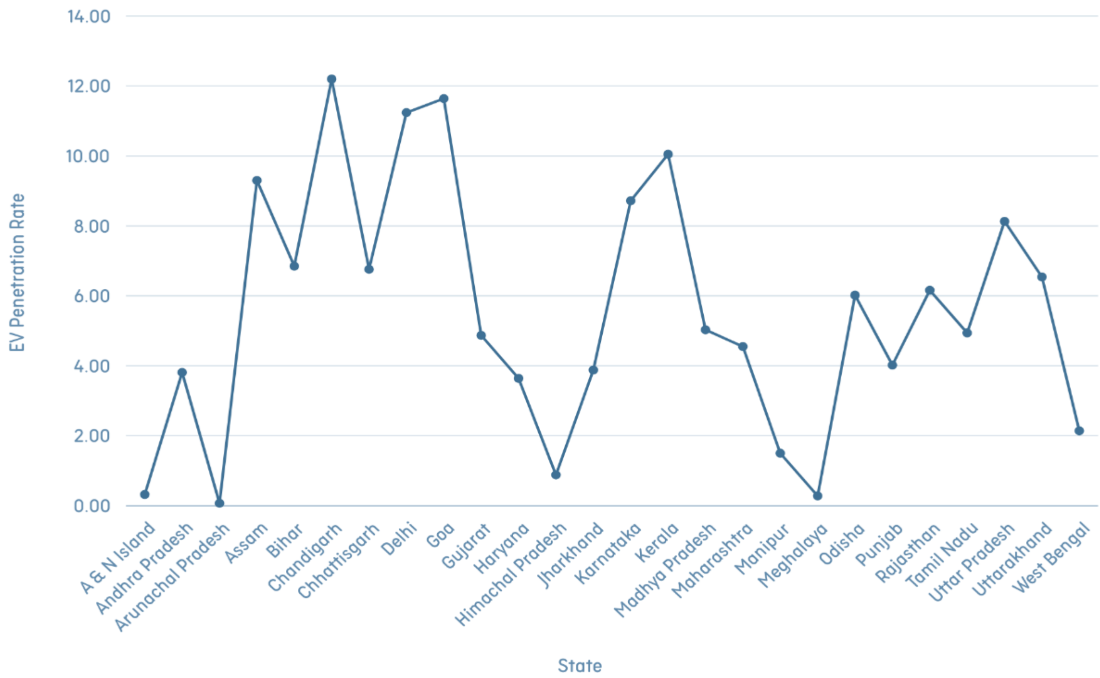


Figure 1.1: Why EV is important for India (KPMG, 2020)

The development and improvement of road transport services have fuelled the socio-economic development of fast-growing countries like India. This has, however, unleashed environmental externalities where 12% of the emissions that are energy-related in the country can be attributed to the road transportation sector (International Energy Agency, 2023b). As a crucial measure to reduce its environmental footprint, India steers its efforts towards electrification in the transport sector (International Energy Agency, 2023b). As one of the leading players in unit EV sales, global EV penetration is likely to be impacted by any movement in EV volumes in India (KPMG, 2020). Setting specific goals for EV adoption, the Government of India (GoI) introduced the 'EV30@2030' target. It aims for *"30% of newly registered private cars, 40% of buses, 70% of commercial cars, and 80% of 2-wheelers and 3-wheelers to be electric by 2030"* (Krishna & Ahmad, 2023, para. 1).

However, the adoption and deployment of EVs in India are still evolving (Chaturvedi et al., 2022). The existing literature has focused on EV technology, charging infrastructure, and financial models, leaving a gap in understanding the influence of regional nuances in impacting the EV growth trajectory. Although there are shared national goals, the micro-level impact of state and city-wise policies on directing EV growth remains underexplored. The disparities in EV regulations, incentives, subsidies, and variations in planning for EV demands based on geographical locations, are evident from the existing case studies in India (V. Singh et al., 2022).

Although India developed socio-economically, the different regions do not share the benefits of this socio-economic development equally (Goli et al., 2013). All major states have promoted the adoption and deployment of EVs and yet the penetration rate of EVs differs in each of these states. Graph 1.1 illustrates the penetration rate of EVs categorized by states recorded until the year 2023.



Graph 1.1: Heterogeneous EV adoption by the different states (Data Source – Vahan Dashboard)

Comparative studies have been more common at the national and international levels and this uneven distribution at the subnational level has not been much looked into (Shao & Mišić, 2023). The study hence undertakes a comparative approach to probe into the possible factors that explain the difference in the deployment patterns and determine how the states leverage their unique contexts to improve EV deployment.

This uneven adoption across states makes it important to understand the specific conditions that lead to higher deployment in some over others. Therefore, this thesis examines the fundamental role of regional influences in determining the adoption and deployment patterns of EVs in the context of India. Beyond the predominant emphasis on engineering and economics, this research considers the complexities of socioeconomic regional nuances and policy dynamics (Schwanen et al., 2011) both that accelerate EV diffusion and restrict the use of ICEVs. The study aims to understand the configuration of regional policies and socioeconomic conditions that co-occur to produce a certain outcome. These conditions are crucial for the diffusion of new technologies, particularly in the early stages when they compete with incumbent technologies (Zimm, 2021).

1.3. Research Aim

The thesis aims to conduct a qualitative comparative analysis of regional heterogeneity in EV adoption to understand the causal complexities in a cross-case setting. This identifies all possible configurations that produce the outcome of interest. The thesis is guided by the main question:

Which combinations of state-level EV policies and local assets are sufficient for a high adoption of electric vehicles (EVs) in Indian states?

This core research question is explored by delving into three sub-questions:

- *Which pathways lead to high EV penetration in the consumer market?*
- *Which pathways lead to high EV deployment from the industry perspective?*
- *What are the identified patterns between the states with high EV adoption reinforced through demand (consumer) versus supply (industry) side factors?*

1.4. Scope and Limitations

The study provides in-depth insight into EV adoption across the states in India, with a focus on BEVs in the private automobile, intra-para transit, and public transport sectors. Aligning with the concept of causal complexity in EV adoption demonstrates the different combinations of conditions that give the desired outcome. However, it also addresses certain limitations.

The study does not focus on long-term effects or base the outcome on the projected adoption rate to compare it to the targets set by the state government. This makes the study a snapshot rather than a forward-looking evaluation.

The incentives offered by the states refer to the policy documents and not the on-ground implementation. Therefore, the result does not fully account for the inherent gap between policy formulation and implementation. This could also lead to overestimation of policy effectiveness.

While the study identifies associations between conditions and outcomes, with the lack of a longitudinal approach, determining causal inferences may not be definitive.

Finally, the study excludes heavy-duty vehicles, and hence, the results do not reflect the entire spectrum of EVs in urban areas. With the same nationwide technological standards and market domination by similar players, vehicle-related factors do not vary from state to state. Hence, the scope here is limited to policy, socioeconomic, infrastructural, and industry factors that vary across regions.

2. Literature review and hypotheses

"New paths are portrayed as being embedded in place-specific conditions and regional capabilities, which are often inherited from past rounds of regional development"

- Trippl et al., 2020, p. 190

2.1. EV in India

Technology has spearheaded the EV revolution, allowing players to leverage the technical niche (KPMG, 2023) but the transition from ICEVs to EVs is also an interplay of regional assets and policy characteristics that stimulated this transition (Nilsson & Nykvist, 2016). While GoI has shared national goals, implementing laws and initiatives that facilitate the switch to EVs falls under the scope of state and local governments. This decentralized approach reinforces the significance of distinct regional features in influencing patterns of EV adoption. For instance, regions with severe air pollution and traffic problems, not only implemented EV adoption incentives but also prioritized ICEV use restrictions (Christensen & Salmon, 2021). As highlighted in Rosenberg (1982), new technology is often not cost-effective in the early stages making policy support imperative to push adoption. Similarly, GoI spearheaded the shift to EVs with national-level initiatives focusing on market and market actors.

2.1.1. Roadmap to EV transition

The Automotive Mission Plan was launched in 2006 and set out the course for the automotive industry over the following ten years (Ministry of Heavy Industries & Public Enterprises, 2006). Subsequently, in 2008, the players in the EV industry united under the Society of Manufacturers of Electric Vehicles (SMEV) to lobby for tax breaks and government policies that would encourage the widespread use of EVs (Dutt, 2023). By promoting sustainable transport alternatives to reduce emissions, the Low Carbon Mobility Plan introduced in 2010, pioneered the integration of EVs into the mobility ecosystem. Further, in efforts towards increasing the share of the automobile manufacturing industry in India's GDP and improving fuel security, the National Electric Mobility Mission Plan (NEMMP) 2020 was introduced in 2012 (KT & Banerjee, 2022), marking yet another milestone. Both the phases (2015 & 2019) of the Faster Adoption and Manufacturing of Hybrid and Electric Vehicles (FAME) Scheme, offered subsidies, incentives, and Goods and Service Tax (GST) reduction to hasten the production and manufacturing of EVs (Digalwar, Saraswat, Rastogi, & Thomas, 2022). Between 2014 and 2019, EV start-ups raised around USD601 million in venture capital with banks, NBFCs, OEM-owned captive vehicle financiers, and others as key players (NITI Aayog & Rocky Mountain Institute, 2021). The launch of the Production Linked Incentive Scheme (PLIS) to bring down the ACC battery prices in 2021 (IEA, 2023), along with the introduction of multinational corporations such as Tata, Ola, and Tesla where technology drives the momentum in this domain (KPMG, 2023), marked the mainstreaming of EVs in the incumbent landscape. Moreover, initiatives by the national authorities to set up charging kiosks on highways and petrol pumps and networks of charging infrastructure across the country, along with the 'Go Electric' campaign (Digalwar, Saraswat, Rastogi, & Thomas, 2022), encourage the widespread adoption of EVs (The Energy and Resources Institute (TERI), 2022). This roadmap outlines the role of policy, industry innovation, consumer background, and infrastructure in upscaling EV adoption, accelerating a shift towards electrifying mobility. These national initiatives are complemented by individual state-level EV policies. The states have set individual EV objectives and specific policies to cater to the EV30@30 goals.

2.1.2. EV segments transitioning this shift

Cities in India exhibit diverse mobility patterns that are generally guided by the size of the regions. While public transport and NMT have a higher mode share in larger cities, smaller cities are dominated by private vehicles, mostly 2-W followed by 4-W. Statistics show the spiraling growth of private vehicles in the market making it imperative to counter the negative externalities (Harikumar & Seth Block, 2019). The electric mobility market has the potential to counter these issues and take up a substantial market share in the Indian automobile segment. Light-duty vehicles are spearheading this transition in India. Based on data availability and the presence of policy conditions for these light-duty vehicles, BEV categories analyzed in the study are 2-wheelers including mopeds, motorcycles/scooter-with sidecar, motorized cycles (cc>25cc), scooters; 3-wheelers including personal, goods & passenger, e-rickshaw, e-rickshaw with cart; 4-wheelers including motor car and motor cab; and buses including educational institution bus, public & private omnibus.

Unlike the global EV leaders, 2-W represents the largest automotive segment in India. The size of this segment and its economic viability have led to E2W dominating EV sales. The elimination of range anxiety and its affordability drives the growth of this segment, especially in short-distance commutes. The 3-W segment represents the last-mile or intermediate public transport, used mainly for intra-city commutes. The informal public transport segment bridges the demand gap caused by the unavailability of proper public transport in most cities. As an accessible and affordable option, the IPT regime holds a prime spot in the Indian transport system. Moreover, E3W has been identified as a viable option with a lower TCO than its ICE counterparts (V. Singh, Doddamani, et al., 2022). The E4W segment gained momentum especially after the pandemic due to increasing fuel prices and a growing need for personal mobility. Electric cars are becoming an important growth market for manufacturers especially with the multiple models present such as car leasing, subscriptions, etc. also providing scope for new entrants. A recent study by the McKinsey Centre for Future Mobility (Goswamy et al., 2023) also shows consumer willingness to shift to EVs and also preference for BEVs over other models of EVs. Finally, electric buses were deployed in India with the initiation of the FAME 1 scheme (V. Singh, Doddamani, et al., 2022). However, due to the lack of technical support by transit agencies to maintain and operate these e-buses, the expansion of public transport has been very limited in Indian regions.

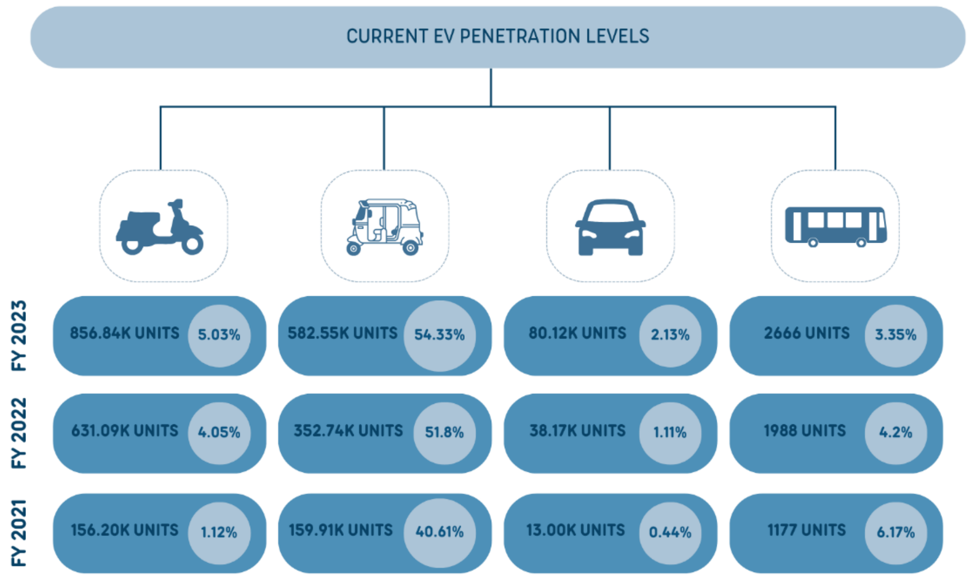


Figure 2.1: EV penetration of the different categories of BEVs (Data Source – Vahan Dashboard)

The budding EV ecosystem in India comprises a cross-industry collaboration amongst the different organizational levels. The key players in the Indian EV ecosystem include original equipment manufacturers (OEM), auto component providers, battery manufacturers, power generators, government organizations, infrastructure network players, industry stakeholders, and consumers (Rong et al., 2017). Catering to these actors, the policies are distinctive and uniquely target these players. Therefore, it is imperative to understand the varied policy mechanisms driving this shift.

2.2. Government's Role in Early EV Adoption - Policy Mixes

Differential policy impacts can be observed due to different target groups. Therefore mixing multiple policy instruments has been proposed as a method to accelerate EV adoption (Li et al., 2020). Given the differential nature of policy and local contexts, the incentives and regulations offered can be broadly categorized into demand and supply policies. These policies are in the form of incentives, concessions, and regulatory mandates. The policy initiatives address all these BEV categories from a consumer and the industry perspective for manufacturing and research. India is heavily reliant on foreign markets for procuring raw materials (for batteries) which is a major reason for a higher Total Cost of Ownership (TCO). Therefore, policies supporting localized manufacturing also address consumer roadblocks supplemented by demand-side incentives (Indian Venture & Alternate Capital Association et al., n.d.).

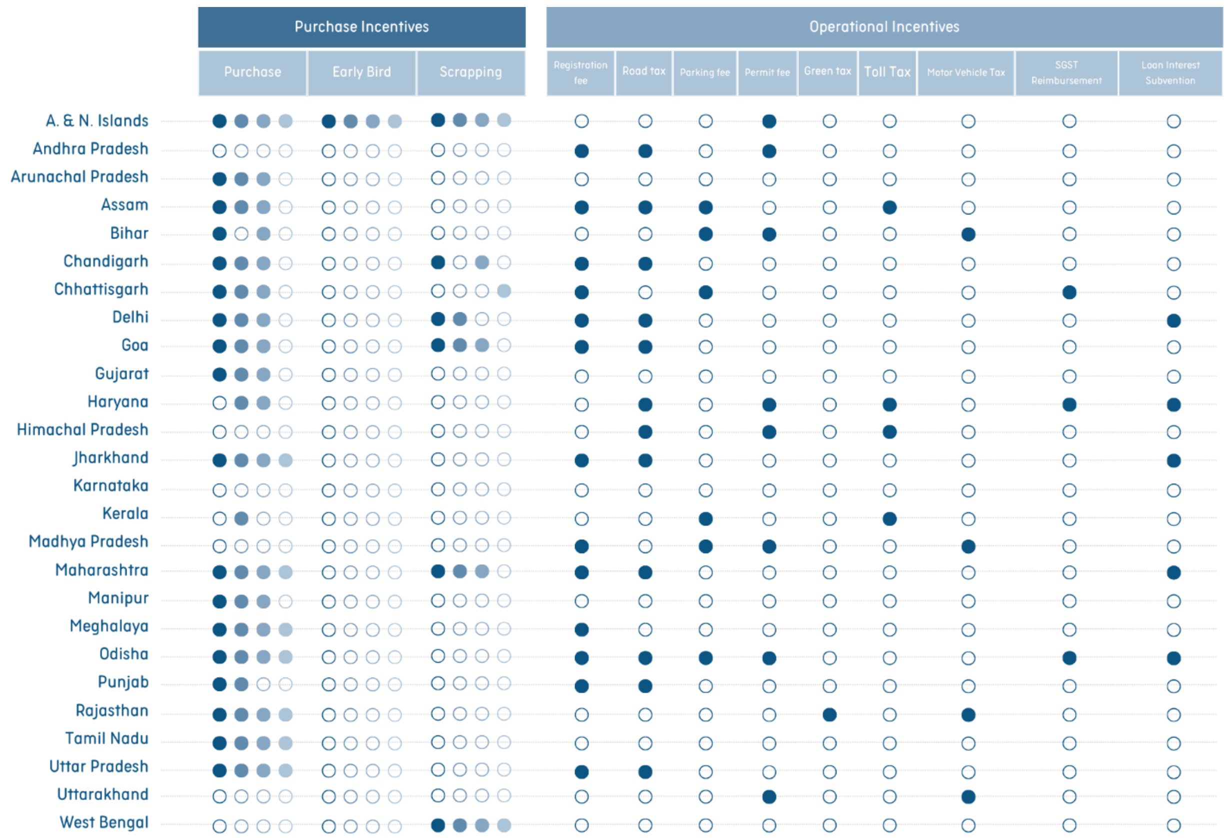
Previously, research has emphasized the role of infrastructure strategies, financial incentives, non-fiscal incentives, and other policy initiatives (Ter Horst, 2015). However, the focus of these studies has been on the way different policy instruments affect EV adoption individually (Li et al., 2020). Here, the scope of research is extended to policy mixes, adhering to Rogge and Reichardt's (2016) research that emphasizes the need to combine policy instruments to analyze their impact on technological change. The reliability of policy mixes shows whether the different government levels support the EV objectives and the comprehensives reflect whether the government has included all contiguous policies. Compared to the studies that limit the scope of understanding the effect of individual variables, a comprehensive examination of the policy mixes and regional assets provides better inferences in the context of the growing use of EVs.

Prioritizing policies to establish BEVs as a mainstream transport option has been a recent initiative. Early adopters of EVs can be found in regions that offer enticing policy incentives. While the demand incentives help in the early stages of EV development by helping them enter the incumbent ICEV market and be more accessible to the consumers, supply incentives further help in establishing an EV ecosystem by strengthening within-state manufacturing and innovation. Therefore, a combination of supply and demand side policy instruments is crucial for deploying electric mobility. Given the policies' differential mechanisms and target groups in the EV ecosystem, it is imperative to understand the workings of these policies separately.

2.2.1. Demand-Side Policies

EV adoption is restricted due to certain consumer barriers like limited driving range, higher purchase costs, and a lack of EV awareness. To overcome these barriers, the demand-side incentives support the development of the EV market, especially in its earlier stages. Policies can be either purchase-based or use-based (Langbroek et al., 2016). While the former aims to reduce the high upfront purchase costs, the latter aims to increase on-road adoption of EVs. Use-based or operational incentives are usually non-financial and require an apt regulatory framework and enforcement capacity for effective deployment (Kanuri et al., n.d.). The purchase incentives introduced by the different states supplement the national-level FAME schemes. Demand is mostly driven by personal attitudes and decisions which are influenced by concessions provided by the government. A comparative overview of these government initiatives is summarised in Figure 2.2. The purchase incentives differ for each category of BEVs while the operational incentives are the same irrespective of the BEV category. The upfront financial incentives offered can be categorized into purchase, early bird, and scrapping incentives. The purchase incentive provides a capital subsidy right during the purchase of the vehicle while the early bird incentive further reduces the cost if purchased during a certain period. To encourage the shift from ICEVs, the government also provides a scrapping incentive that entitles the vehicle owners to receive a sum of money on surrendering their ICEVs. Purchase incentives are widely offered in most states with variations in the categories it is offered across. The early bird incentive is only offered in Andaman and Nicobar Islands and the scrapping incentives are also not widely offered. The operational incentives show a diverse pattern across states. Regions like Assam, Odisha, Haryana, and Himachal Pradesh provide a range of concessions while Arunachal Pradesh, Karnataka, Manipur, Tamil Nadu, and West Bengal do not focus on operational incentives. There is a general tendency in regions to emphasize purchasing over operational incentives. This implies that reducing upfront purchase costs has been prioritized to stimulate EV adoption. Moreover, road tax and parking fee exemptions are relatively more common compared to SGST reimbursement or loan interest subvention.

Conventional ICEVs have superior features compared to EVs and a lower purchase cost. Although the purchase costs of EVs are higher, the operational costs are lower compared to ICEVs. This shift in consumer perspectives is brought about by support mechanisms such as promotions/ marketing or awareness, education, and an individual's purchasing capacity. Therefore, the impact of these policies is influenced by demographic variables like income and education level.



Addressed in policy : ● - Electric 2 Wheelers ● - Electric 3 Wheelers ● - Electric 4 Wheelers ● - Electric Buses ○ - Not addressed in policy

Figure 2.2: Matrix of EV demand incentives (Source - Constructed by author)

2.2.2 Supply-Side Policies

An overview of the state policies emphasizes strengthening the supply side. All the state EV objectives focus on improving infrastructure, manufacturing, and R&D to create an EV ecosystem. It is also aiming to attract investment and generate employment in the state. This comprises charging infrastructure and industry incentives. These incentives cater to the manufacturers, researchers, and industries to enhance the EV value chain. The focus is primarily on charging infrastructure, manufacturing, battery technology innovation, and industry-academia partnerships to improve local supply chains. Presently, most state-level capital subsidies, concessions, and free land allocation are geared towards enhancing public charging infrastructure. Urban development authorities and energy department agencies are planning and regulating this infrastructure. A regional difference based on the geographic location of industries is also observed where states offer lower subsidies in more developed regions and higher subsidies in underdeveloped regions (Kanuri et al., n.d.). The incentives and concessions subsidize capital and infrastructure costs, and research and human resource development. The matrix below (Figure 2.3) summarises the incentives addressed in the policy documents of each state. From a supply perspective, investments are made in creating charging infrastructure, manufacturing, and research in advancing EV technology. To encourage in-state manufacturing, the state allocates land either for free or at a marginal lease rate to industries. To support research in this field, the state offers research grants, incentives to set up labs, and stipends for training professionals in this field. To improve the infrastructure, the state offers capital subsidies or incentives to set up PCS or a complete GST reimbursement on the initial amount. Some states also offer land to set up PCS on minimum rental leases or provide rebates on property tax. Some states also exempt providers from electricity duty fees or provide a reduction in energy charges.

	Charging Infrastructure							Manufacturing	R & D		
	Capital Subsidy	Incentives for setting up	GST Reimbursement	Reduction in energy charges	Electricity duty exemption	Minimum Rental Lease	Property Tax Rebate	Land Allocation	Research Grant	Incentives for setting up	Stipend for Training
A. & N. Islands	○	●	○	○	○	○	○	○	○	○	○
Andhra Pradesh	○	●	○	○	○	○	○	○	●	●	○
Arunachal Pradesh	●	○	○	○	○	○	○	○	○	○	○
Assam	●	○	○	○	●	○	○	○	○	○	○
Bihar	○	●	○	○	○	○	○	○	○	○	○
Chandigarh	○	●	●	●	●	○	○	○	○	○	○
Chhattisgarh	●	○	●	○	○	●	○	○	○	○	○
Delhi	○	●	●	○	○	●	○	○	○	○	○
Goa	●	○	○	●	○	●	○	○	○	○	●
Gujarat	●	○	○	○	○	○	○	○	○	○	○
Haryana	●	●	●	○	○	○	○	○	○	○	○
Himachal Pradesh	○	○	○	○	○	○	○	●	○	○	○
Jharkhand	●	○	○	○	○	○	○	○	○	○	○
Karnataka	○	●	○	○	○	○	○	○	○	○	●
Kerala	●	○	○	○	○	○	○	○	○	○	○
Madhya Pradesh	●	○	○	○	○	○	○	○	○	○	○
Maharashtra	○	○	○	○	○	○	●	○	○	●	○
Manipur	○	○	○	○	○	●	○	○	○	●	○
Meghalaya	○	○	○	○	○	●	○	○	○	○	○
Odisha	●	●	●	○	○	○	○	○	○	○	○
Punjab	●	○	○	○	○	○	○	○	○	○	○
Rajasthan	○	○	●	○	○	●	○	○	○	○	○
Tamil Nadu	○	●	○	●	○	○	○	○	○	○	○
Uttar Pradesh	●	○	○	○	○	○	○	○	○	○	●
Uttarakhand	○	○	○	○	○	○	○	○	○	○	●
West Bengal	○	●	○	○	○	●	○	○	○	○	○

● - Addressed in policy ○ - Not addressed in policy

Figure 2.3: Matrix of EV supply incentives (Source - Constructed by author)

It is evident from the matrix that investing in the improvement of charging infrastructure is a major approach adopted by regional governments followed by creating partnerships to encourage research and development in EV technology. However, investments in manufacturing are not a common strategy opted by the government, given the high costs of investment manufacturing entails. This also highlights the role of the private sector as a major stakeholder and their expertise and investment in improving EV adoption.

While these policies play a major role, their effectiveness varies regionally due to local factors.

2.3. Regional Factors Affecting EV Adoption

"Institutions shape, but also are shaped by the places they are embedded" (Trippl et al., 2020, p. 191). Literature has found contextual factors to be influential in EV adoption outside of technological and psychological factors (Sierzchula et al., 2014). Recent literature by Pamidimukkala et al., (2024) investigates 537 research papers to reveal that socioeconomic and contextual factors affect EV adoption. It is quite evident in the case of India that there is heterogeneity in EV adoption among the states (refer to Figure 1.2) and state-specific factors can explain these regional disparities. The direction of policy impact is determined by the state's local context which explains the heterogeneity despite the enforcement of a similar set of policy initiatives. This study refers to factors such as regional or local conditions that directly impact policies as regional assets. Moreover, the local context determines how each region responds to specific policies.

Policy and regional factors that have often been associated with low EV penetration in India include range anxiety, high upfront costs, lack of consumer awareness, and absence of charging infrastructure and technical standards for the same (Jain et al., 2022). The adoption behavior can be shaped by the attributes of the technology, the adopters, and the social-economic environment. The adoption behavior of EVs is commonly assessed, considering various factors such as economic, environmental, and demographic aspects (Jia et al., 2020) that are discussed in the following sections.

2.3.1. Consumer Perspective

Although under-emphasized in transitions theory, consumer or user acceptance is imperative for widespread technological diffusion on a scale simply beyond adoption (Steinhilber et al., 2013). While consumer adoption is partly driven by government incentives, user acceptance is also driven by a range of factors like perceived environmental benefits, the cost-effectiveness of EVs, and an individual's attributes.

The literature emphasizes the significance of socioeconomic characteristics in defining disparities between EV adopters and non-adopters. At the consumer level, specific population segments are more inclined toward embracing this new newer technology of electric vehicles. Such segments typically comprise individuals with higher income and educational levels. Adopters often belong to demographic cohorts such as males and middle-aged individuals. However, demographic characteristics have been proven to be weak indicators of sustainable consumption behavior (Wang et al., 2022, as cited in Fraj & Martinez, 2007; Midgley & Dowling, 1978). Additionally, EV adopters demonstrate a heightened awareness of environmental issues, social norms, and recognition of national energy security concerns (Zimm, 2021). It can therefore be summarised that consumer intentions are driven by their income, education, environmental awareness ease of use, and affordability (Bajpai et al., 2024; Sierzchula et al., 2014). As affordability is measured by one's income and income is correlated to education and awareness, the regional consumer attributes are narrowed down to:

- **Income**:
  The study by Bajpai et al., (2024) highlights factors such as incentives provided by the government, availability of infrastructure, education, and income levels that correlate with the growing use of EVs. Apart from EV-specific factors, the uptake of new technology is mainly driven by consumer traits. Because of improved access to resources, information, and awareness of environmental concerns, EV use can be correlated to the income of EV owners. While some studies have proved that income levels have a strong effect (Hidrue et al., 2011, Plötz et al., 2014, Zhuge and Shao, 2019 as cited in Bruckmann et al., 2020), some studies at the national level have contradictory views (Sierzchula et al., 2014, Li et al., 2017c as cited in Bruckmann et al., 2020). This proves the importance of other conditions that direct the influence rather than individual factors.
- **Charging Infrastructure**:
  Higher BEV adoption rates have been observed in regions with a well-structured network of charging infrastructure. Therefore, public charging infrastructure has been an integral policy instrument to promote BEV adoption (White et al., 2022). This is complemented by studies that emphasize that inadequate charging infrastructure has been a major barrier to EV adoption (Lim et al, 2015; Barisa et al., 2016, Berkeley et al., 2018, Lin and Wu, 2018). This brings down user comfort and flexibility thereby lowering the attractiveness of EV use. As EVs are still a small market and their maintenance aspects are still not fully specialized, it explains the reluctance of consumers to shift from ICEVs. This can be overcome by developing robust charging infrastructure that would instill confidence in consumers, reducing range anxiety (Rauh et al., 2015 as cited in, Jain et al., 2022).

Interestingly, the industry perspective also provides a critical vantage point as discussed in the following section, as their enablers and inhibitors are crucial in the EV transition process (Shankar & Kumari, 2019).

2.3.2. Industry Perspective

Policy instruments are also influential to the EV supply chain, creating a conducive ecosystem for the EV market. Studies suggest that factors like the industry composition of specific regions influence the adoption of EVs. For instance, the significance of the automotive manufacturing sector influences the demand for EVs in that region by creating a new supply chain structure and garnering R&D investments that sustain the growth of the EV market (Jagani et al., 2024). As also discussed in section 2.3.1, the network of charging stations is crucial in determining user's flexibility and comfort in using EVs. This has been identified to be particularly the case in countries like India (Murugan & Marisamynathan, 2022). To address this, the government offers incentives and mandates industry players to push infrastructural developments.

- **Economy:**
  A recent study by Ruoso & Riberio (2022), proves a strong correlation between per capita regional GDP and EV adoption. Richer regions are early in adopting new technologies (Lee, 1990) as they are open to taking risks or can deal with their underperformance (Greenhalgh & Rogers, 2010). Regional wealth is a key enabler and a determinant in understanding the speed of innovation diffusion in countries (Dekimpe et al., 2000). A strong financial background also helps these regions to bounce back from externalities.
- **Industry:**
  Policies enhance the adoption process by particularly targeting the regional industries where it aims to foster collaborative manufacturing systems along with other services such as technological research, venture capital provision, labor training, etc. In addition to a large potential market, EV production is an attractive opportunity in regions with manufacturing resources that can be deployed for EV (Scott, 1995). The presence of coordinating establishments eases knowledge transfer and resolves region-wide problems benefitting the regional industrial systems. Also, a study by Li et. al (2022) proves that companies are prone to be attracted to regions that have relevant industrial clusters and a skilled workforce.

Therefore, the growth of EVs can be attributed to the presence of government policies, fostering manufacturing and innovation, and enhancing consumer interest. Considering the intricate interplay between policy and regional factors, the study proposes a notion of configuration that approaches the EV phenomenon as a constellation of interconnected elements.

2.4. Configurational Approach and QCA

EV adoption has often been looked at through the ideologies of policy diffusion, diffusion of innovation theory or theory of planned behaviour. These studies have been influential in identifying individual variables that drive the growth of EVs. On the other hand, previous literature has highlighted the multifaceted nature of drivers and barriers to EV adoption, underscoring the need for a comprehensive ecosystem approach (Berkeley et al., 2018) rather than addressing individual factors in isolation. To enrich the academic discourse and for effective policy strategizing for the facilitation of EV transition, researchers emphasize the significance of an integrated review (Berkeley et al., 2018; Kumar & Alok, 2020), basing this study on a configurational approach.

The configurational approach is guided by the principle that the whole is better comprehended from a systemic perspective (Geels & Turnheim, 2022). Instead of using variables and correlations, the configurational approach relies on sets and set–subset relationships (Fiss et al., 2013) aligning with the ideologies of QCA. Based on QCA, this approach has contextual effects at its core, suggesting that the impact of the presence or absence of causal conditions or configurations depends on the context. Therefore, instead of assuming an incremental relation between conditions, it views it as positive or negative complementarities (Fiss et al., 2013). Moreover, this approach is relevant for the study of EV transitions given the attention to the concept of equifinality, implying that different initial conditions and pathways can result in the same final system state (Flood, 2017).

Being based on set theory and following the configurational approach, QCA makes it possible to determine the configurations resulting in the desired outcome. An integral part of QCA is the selection of cases and conditions. Cases are the units of analysis that are locus in the research. The conditions are the factors that influence the outcome and can be compared to the variables in a statistical analysis. In QCA, each condition and outcome is conceptualized as a set. A set is a collection of cases that share specific characteristics. Each case can then be a member of the set or not. QCA uses set membership to categorize these cases as per the presence or absence of certain conditions. As described by Ragin (2008), the conditions can be classified as necessary or sufficient based on the subset and superset relationship. If one set of cases with a certain outcome is a smaller part of another set of cases with a certain condition, then the condition set is a superset of the outcome set. That is, each case with a given outcome also has a particular condition. This indicates that the outcome cannot occur unless the condition is met (a necessary condition). If every case that has a certain condition also leads to the outcome, then the condition set is a subset of the outcome set. This indicates that the condition is sufficient for the result. It further addresses conjunctural causation where multiple conditions come together to produce a certain outcome. QCA uses Boolean algebra to minimize complex configurations by creating a truth table and then minimizing these solutions into the simplest expressions to explain the outcome.

2.5. Research Framework

To explore which specific pathways lead to successful EV adoption, the study follows a framework that does not look at policies as isolated systems, but rather catalyzed by regional assets. Combining and modifying the frameworks from the reviewed literature, the study proposes a model that examines the interaction between policy instruments and contextual factors such as socioeconomic, infrastructural, and industry conditions. The framework ensures a comprehensive outlook on EV adoption and deployment by distinguishing the user and industry perspectives. Regional assets along with policies shape EV adoption. Here, these assets are either considered as enablers or constraining factors in shaping the influence of regional policies. To draw comparisons, the conditions explored in this study are all at the state level and are unique to the regions as the national level policies do not vary state-wise. Therefore, the study does not focus on national-level policies and incentives as the differential state-level policies complement the common national policies to drive the EV adoption trajectory.

The integrated framework intends to explore configurational pathways that lead to higher EV adoption in the supply and demand markets and the synergy between policy instruments and regional factors.

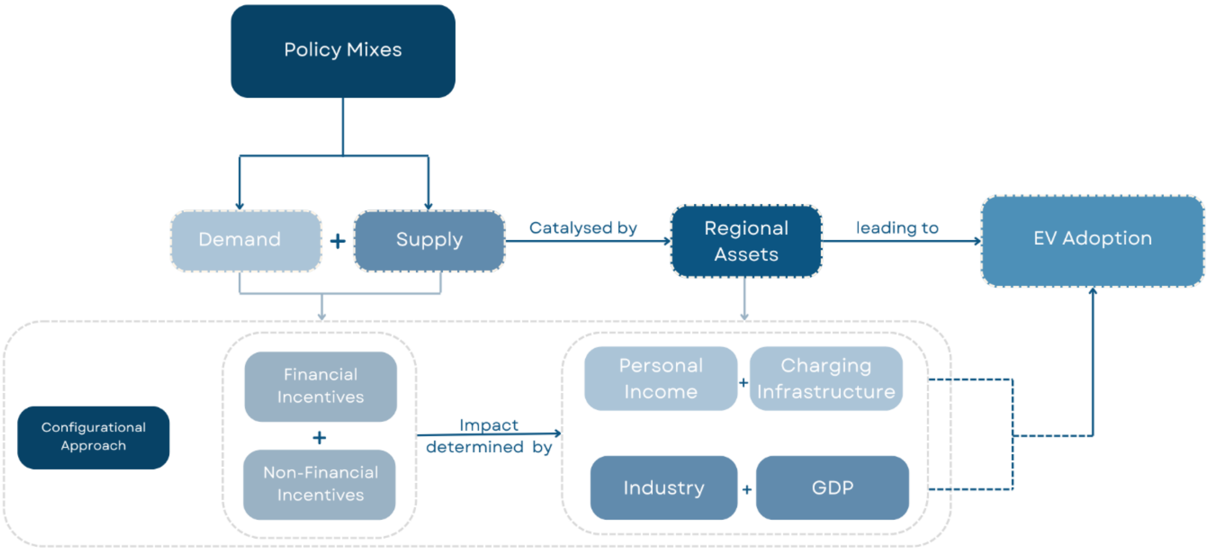


Figure 2.4: Research Framework

2.6. Research Opportunities and Hypotheses

In the landscape of EV adoption, literature has emphasized the role of individual policy instruments over policy mixes. This often leads to oversimplified recommendations. Several studies have either taken a purely qualitative approach such as Berkeley et al., 2018, or a purely quantitative one such as Hidrue et al., 2011. Moreover, the cases of Norway, California, and China (Lemphers et al., 2022) also show the differences between a consumer market and a producer market. The limitations of the previous studies provide opportunities for this thesis. To fill the gap, the study focuses on a combination of policies and the role of regional assets in influencing EV adoption. This calls for an assessment of the role of policies from a demand or consumer perspective and a supply or innovation perspective separately. Through these conditions, this thesis provides insights into the drivers of regional variations in EV adoption across diverse regions of India. The policies present an effort to improve India's EV ecosystem which calls for the need to study the demand and supply aspects to understand the shift in consumer usage and the localization of production and innovation. Therefore, the study aims to test the following hypotheses:

H1: *EV adoption is driven by distinct configurations combining policy instruments and regional assets, rather than individual factors in isolation.*

H2: *Financial and non-financial incentives have a positive effect on EV adoption.*

H3: *High personal income and public charging stations are essential for higher EV penetration.*

H4: *The presence of an EV industry and higher GDP is essential for higher EV adoption.*

3. Research design, methodology

“Thinking without comparison is unthinkable. And, in the absence of comparison, so is all scientific thought and research.”

- Swanson, 1971, as cited in Ragin, 1987, pg. 1

The study examines the relationship between policy, and region-specific factors and EV adoption in the Indian states, taking forth a case-based approach. Through an explanatory study, the thesis aims to determine the configuration of conditions that lead to a higher outcome of EV adoption. This thesis adopts a Qualitative Comparative Assessment to analyze the configurational relationships between region-specific socioeconomic and state-level EV policy conditions that determine the adoption trajectories of EVs. QCA enables this systematic comparison of cases by capturing the complexity and nuances of the research problem (Verweij & Gerrits, 2016). In studying regional variations, QCA helps analyze how different combinations of socio-economic and policy conditions influence EV adoption in the Indian states.

3.1. Why QCA?

QCA combines a case-specific focus as often seen in qualitative analysis and the ability to generalize as allowed for by quantitative analyses (Rihoux, 2006). Reflecting the focus of the study, QCA enables one to determine a combination of conditions that provide the outcome from a comparative perspective. It has been applied to the study of these Indian states given its affinity towards medium-N comparisons, which are too large for traditional comparative studies. Moreover, policy changes are set-theoretic. QCA allows us to examine this conjectural causation, where it is not a single condition or policy but a combination of these that leads to the desired outcome. It also accounts for equifinality, as observed in the Indian states with different objectives and socio-economic backgrounds, where different pathways lead to the same outcome. Finally, reflecting these aspects and causal asymmetry, QCA accounts for causal complexity (Mello, 2023). Further, it allows the identification of cross-case patterns and multiple causation by providing an in-depth focus on cases. While it identifies localized effects through case-based modelling, post-analysis, it also returns to the individual cases for a more profound comprehension of the results and the sample (Pappas & Woodside, 2021). As most conditions in the context of this research are continuous variables and not binary, fuzzy-set QCA is preferred as it allows for the evaluation of the relative strengths of the conditions. Unlike cs/QCA, set membership in fs/QCA can be anywhere between 0 and 1 making it possible to scale and allow for partial membership (Ragin, 2009).

However, like all research methods, QCA has its limitations. Only those conditions could be incorporated that have uniform data access across all states. The scoring process partly depends on the researcher’s judgment making it subjective. Due to the absence of standardized values, this study opts for a scoring process based on variable distribution that makes calibration similar to statistical analyses as opposed to fs/QCA. QCA is an iterative process that calls for repeated reformulation and data collection which is subject to time and data availability. Finally, one common criticism of QCA is the dichotomization or calibration of qualitative data or non-numeric values as that removes certain details or nuances from the raw data (Baptist & Befani, 2015).

3.2. Case Selection

Here, the states form the cases, denoting the unit of analysis observed at the same point in time. This study bases the case selection on given populations, benefitting from face validity (Mello, 2021). Consequently, all the Indian states and union territories constitute the base population. To avoid the integration of irrelevant cases, the scope condition narrows the study population to regions that have formulated state-specific EV policies and have data available. Therefore, the 26 regions that have published state EV policies are the selected cases for this study.

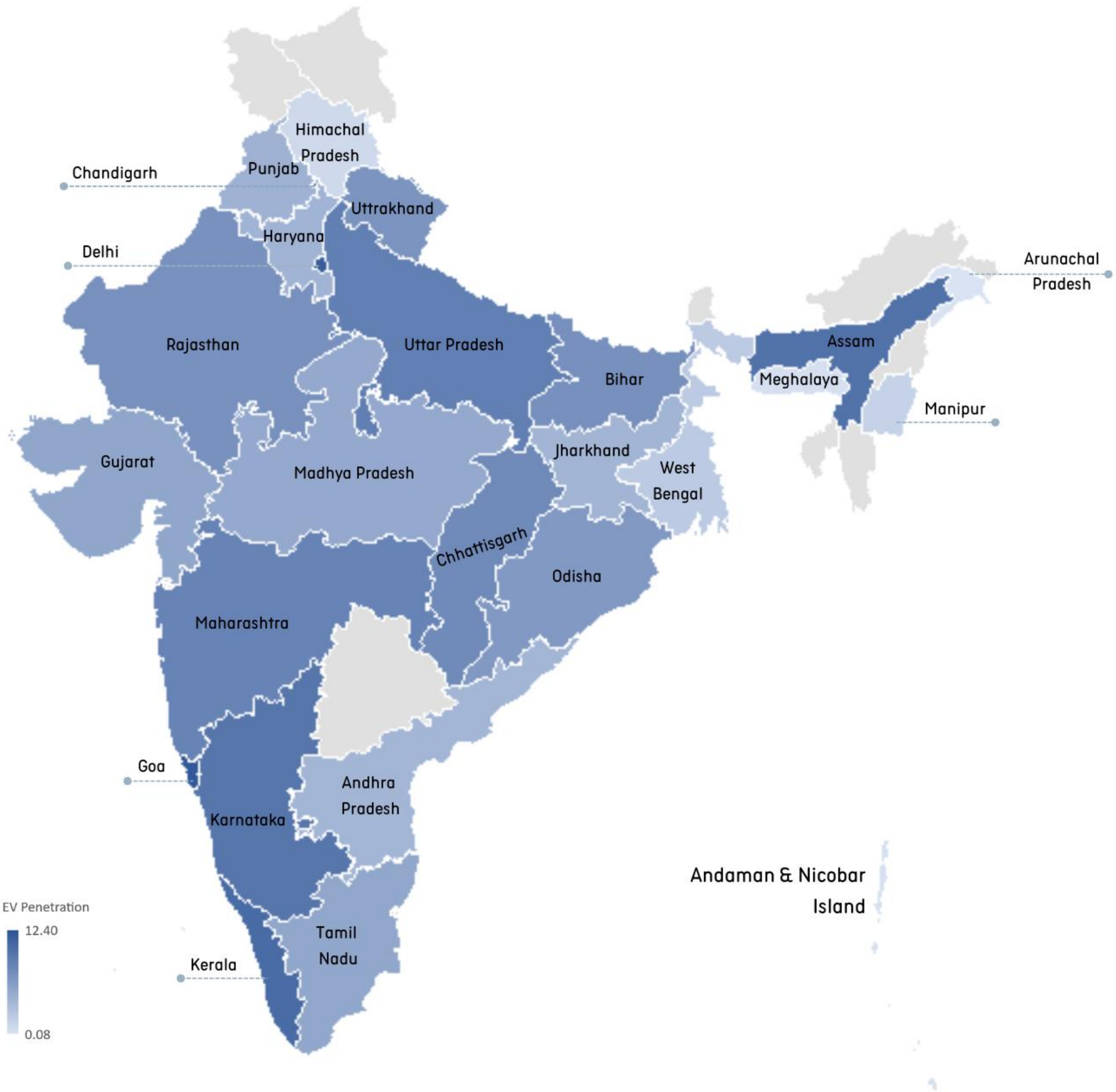
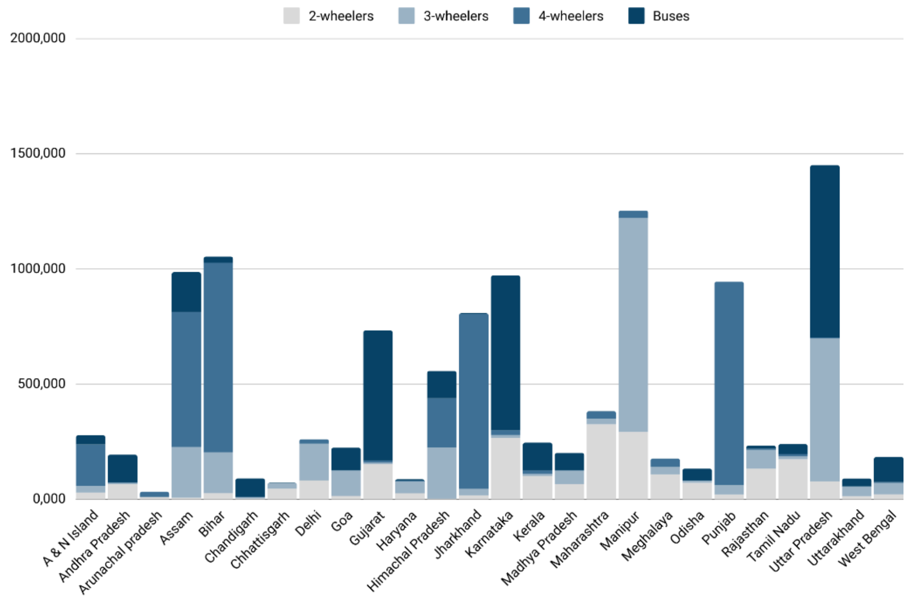


Figure 3.1: Cases included in the study (Source: Constructed by author)



Graph 3.1: State-wise EV registrations in each segment (Data Source – Vahan Dashboard)

These cases differ and are comparable in terms of their market share of EVs, sectoral composition, economic development, size, etc. Using set membership, these cases are categorized based on whether certain conditions are present or absent. In crisp-set QCA, a case can either be completely in (1) or completely out (0) of the set while in fuzzy-set QCA, a case can be completely in (1), completely out (0), more in than out, or neither in nor out (0.5) in a set (Mello, 2021).

3.3. Operationalization

EVs are utilized in road transportation ranging from two-wheelers to long-haul trucks, though their penetration rates vary (Grütter & Kim, 2019). As mentioned in section 2.1.2, this study focuses on 4 categories of BEVs: electric two-wheelers, electric three-wheelers that substitute the IPT regime, electric four-wheelers, and electric buses representing public transport. This study relies on both qualitative and quantitative data from secondary sources. The outcome, EV adoption is calibrated through the number of EVs registered in each of the categories and their penetration rates, as recorded until the year 2023. This data is secured from the official open-source dashboard of the Regional Transport Office of India (Vahan dashboard). The socioeconomic indicators are collected from the census, industry reports and previously published studies. The official gazettes of the state EV policies are utilized for the policy assessment. The reliability and validity of data are ensured through triangulation and cross-referencing.

This study considers the states as cases and the regional characteristics and policy initiatives as conditions. Fs/QCA offers a structured framework for within-case and cross-case comparative analysis of the layered phenomenon of EV adoption (Legewie, 2013). The cross-case analysis examines both cases with high and low levels of EV adoption to better understand the local adoption patterns and the drivers, barriers, and contextual factors that influence them. Following a ratio of approximately 1:5 between cases and conditions ensures that there are sufficient observed cases for each combination (Mello, 2021). Since QCA cannot include a large number of conditions, the critical ones are selected based on the literature.

Conditions	Conceptualization	Data Source
Widespread EV Adoption	The number of EVs registered as of 2023 since the time of EV inception (2014)	Vahan Dashboard
Robust Fiscal Incentives	To make EVs more competitive with traditional ICEVs, the state governments offer incentives. The goal of fiscal incentives is to remove adoption barriers and encourage the purchase and use of EVs until the industry matures and becomes more mainstream (Kanuri, Rao, & Mulukutla, 2021).	EV State Policy Document
Comprehensive Non-Financial Incentives	Local governments do not base their decisions and implementation of policy initiatives solely on financial gains. This condition focuses on regional incentives that provide non-financial advantages to EV users when driving cars with zero emissions in urban areas (Held & Gerrits, 2019).	EV State Policy Document
Extensive Charging Infrastructure	Since the range of EVs is not as long as that of ICEVs, there is significant reliance on well-developed infrastructure for daily needs. Plenty of city administrations have prioritized installing public charging stations (Held & Gerrits, 2019) to improve user comfort.	EV State Policy Document
Diversified Industries	The presence of an EV industry (which would also imply higher employment opportunities) affects the early and non-adopters of EVs (Geny, 2021).	Annual Reports of State Governments
Developed Regions	Higher income implies greater willingness to adopt EVs and better affordability for the users (Geny, 2021) and higher GDP gives more scope for initial investments and stronger financial backing during transitions for the market.	Census, India

Table 3.1: Operationalization table

3.4. Calibration

The collected and processed data is analyzed using R where the initial step is calibration. To bring the collected data to a common scale, the quantitative and qualitative data are scored based on Boolean algebra into 0, 1, or any value in between. The calibration process transforms the collected raw data into crisp and fuzzy set scores to represent the extent to which each case displays a particular condition or outcome (Mello, 2023). This study uses the software-based continuous fuzzy set which is based on the direct method (Mello, 2021) of calibration. For the conditions that lacked standardized measures defining high and low levels of these conditions, relative scoring was done by distributing the values utilizing quantiles to set the thresholds. The conditions do not specify standard measures denoting high or low levels for the specific context of India. As the study aims to do a comparative analysis between the Indian regions, the existing/ collected data is used to determine relative standards for this specific study context – hence the use of quartiles to determine low, medium, and high levels of the conditions. Also, since the creation of infrastructure, policy enforcement, etc. are still under process and haven't reached completion, extrapolating global standards would not yield accurate results in this case.

The outcome condition for both demand and supply QCA has been calibrated by the total number of light-duty BEVs in the category of 2-Ws, 3-Ws, cars, and buses registered until the year 2023 in each of the selected cases. The data was calibrated into a fuzzy set with relative scoring.

3.4.1. Demand Calibration

The penetration rate provides the relative value of the total number of EVs registered to the total number of vehicles registered in the year 2023. Since demand looks at consumer perception and willingness to adopt, this measure allows one to determine the penetration of EVs in the existing vehicle market.

Outcome	Membership Function	Membership Scores
Elevated Share of EVs	The ratio of the total number of electric two-wheelers, three-wheelers, four-wheelers, and buses to that of total vehicles registered in 2023 (EV Penetration)	Fuzzy Set Full membership: States with EV penetration of more than 8.59% fully belong to the set Crossover point: States with EV penetration of 5.94% represent the point of maximum ambiguity. Full non-membership: States with EV penetration less than 4.03% do not belong to the set.

Table 3.2: Calibration of demand-side outcome

To analyze the demand side factors influencing EV adoption, the calibration considers four key conditions: financial and non-fiscal incentives for consumers, a network of public charging infrastructure, and individual income. The financial incentives, literacy rate, and GDP were based on fuzzy scoring while the condition of non-fiscal incentives was based on crisp-set.

Condition	Membership Function	Membership Scores
Robust Financial Incentives	Early Bird, Purchase, and Scrapping Incentives for 2, 3, and 4-wheelers and buses	Fuzzy Set Full membership: States with incentive amounts more than Rs. 19,22,750 fully belong to the set. Crossover point (denoting maximum ambiguity): States with an incentive amount of Rs. 2,51,250. Full non-membership: States with incentive amounts less than Rs. 44,375 do not belong to the set.

Comprehensive Non-Fiscal Incentives	- Road tax, Registration fee, Parking fee, and Permit fee exemption - Rebate on green tax, toll tax, and motor vehicle tax - SGST Reimbursement - Interest subvention on loans	Crisp Set 0 – States with less than 2 categories of 4 of these incentives. 1 – States with more than 2 categories of these 4 incentives.
Extensive Charging Infrastructure	The number of public charging stations (PCS) per 1000 square km	Fuzzy Set Full membership: States with more than 7.63 PCS per 1000 sq. km fully belong to the set. Crossover point (denoting maximum ambiguity): States with 1.85 PCS per 1000 sqm. Full non-membership: States with less than 1.1 PCS per 1000 sq. km do not belong to the set.
Individuals with purchasing power	Per Capita Income for the financial year 2022-2023	Fuzzy Set Full membership: States with per capita income of more than Rs. 2,39,911.2 fully belong to the set. Crossover point (denoting maximum ambiguity): States with a per capita income of Rs. 2,10,439. Full non-membership: States with per capita income of less than Rs. 1,35,569.2 do not belong to the set.

Table 3.3: Calibration of demand-side conditions

3.4.2. Supply Calibration

To comprehend the conditions that improve the market interest of EVs, the absolute number of EVs deployed on-road is a testament to the success of EV transition. The total number of EV registrations provides an absolute measure indicating the size of the growing market in these regions. Therefore, more than the penetration rate of EVs, the total EV registrations capture the effects of supply-side conditions.

Outcome	**Membership Function**	**Membership Scores**
	The total number of electric 2-Ws, 3-Ws, cars, and buses registered as of 2023	Fuzzy Set Full membership: States with EV registration of more than 202,893 EVs fully belong to the set

Widespread EV Adoption		Crossover point (denoting maximum ambiguity): States with EV registration of 78,303 EVs. Full non-membership: States with EV registration of less than 23,810 EVs do not belong to the set.

Table 3.4: Calibration of supply-side outcome

The four key conditions measuring the supply-side conditions influencing EV adoption are fiscal and non-fiscal incentives for setting up charging infrastructure, manufacturing, and R&D, the number of public charging stations, and EV and/or automobile industries in the state. Moreover, the absolute number of EVs on the road is determined by the economic, manufacturing, and R&D capabilities of the state. A membership function was defined for each of these conditions based on monetary compensation at the organization level, policies, etc. to determine the membership scores. The financial incentives and state GDP were based on fuzzy scoring while the conditions of non-fiscal incentives and the presence of EV industries were based on crisp-set.

Condition	**Membership Function**	**Membership Scores**
Robust Financial Incentives	Incentives for setting up charging infrastructure, manufacturing, and R&D units	Fuzzy Set Full membership: States with incentive amounts more than Rs. 19,22,750 fully belong to the set. Crossover point (maximum ambiguity): States with an incentive amount of Rs. 2,51,250. Full non-membership: States with incentive amounts less than Rs. 44,375 do not belong to the set.
Comprehensive Non-Fiscal Incentives	- Land allocation or minimum rental lease for charging infrastructure and manufacturing - Property tax rebates - SGST and electricity duty reimbursement	Crisp Set Full membership: States with incentives addressing either infrastructure, manufacturing, or R&D Full non-membership: States without incentives addressing these sectors
Diversified Industries	The presence of a strong EV industry in the state	Crisp Set Full membership: Presence of the EV industry Full non-membership: Absence of EV industry
	Per Capita Net State Domestic Product for the financial year 2022-2023	Fuzzy Set Full membership: States with per capita GDP of more than Rs.

Developed regions		1,65,829,750 fully belong to the set. Crossover point (maximum ambiguity): States with a per capita GDP of Rs. 99,568,500. Full non-membership: States with per capita income of less than Rs. 65,045,750 do not belong to the set.

Table 3.5: Calibration of supply-side conditions

3.5. Data Analysis

After identifying the financial and non-financial policy interventions and collecting data on the regional factors, the data is analyzed for the fs/QCA using R. The conditions are calibrated and tested for necessity and sufficiency. Then, the sixteen possible causal configurations are described by the truth table and the cases are classified based on the identified logical combinations. The concepts that are essential for the analysis are discussed in this section.

In studying causal complexity, the subset relation serves as the vital set-theoretic relation (Ragin, 2000, 2009), determining if a configuration or a condition is to be construed as sufficient or necessary for the outcome. *"A necessary condition is a superset of the outcome"* (Mello, 2021, pg. 95) implying that every case that holds membership in Y also holds membership in X. Whereas, "*a sufficient condition is a subset of the outcome"* (Mello, 2021, pg. 96) implying that every case that holds membership in X also holds membership in Y.

Acting as the core of QCA, the truth table represents every potential configuration that can be conceived with the given number of conditions (Mello, 2021). The demand and supply side analysis comprises 4 conditions which results in 16 possible configurations (2^4) or rows in the truth table. The conservative, parsimonious, and intermediate solutions are determined based on the minimization of these configurations (Bhattacharya, 2024). On the basis of simplifying assumptions, the intermediate solutions report a shortened and streamlined version of complex solutions. Since the thesis aims to ascertain the core conditions sufficient for high EV adoption, the intermediate solutions work best by presenting the important conditions that cannot be omitted and also account for counterfactuals.

The truth table and the solutions are analyzed based on the following measures of fit:

Consistency: The inclusion score measures the consistency of the configurations that result in the desired outcome. This means that it assesses the extent to which the cases that share a particular configuration can exhibit the desired outcome (Ragin, 2008). In the context of this study, since the values of the outcome are higher than the values of their respective conditions, the outcome is a superset of the conditions. This implies that the conditions are sufficient for the presence of the outcome. For configurations with consistency less than 1, it implies that there are one or more cases about that recipe that do not display the outcome. The threshold has been set at 0.8 for this study.

Coverage: The solution coverage, denoted by covS, accounts for the overall degree to which the conditions explain the outcome. On the other hand, covU, or the unique coverage assesses the unique explanatory power of a configuration. In this case of sufficient conditions, it explains how much of the empirical evidence is uniquely explained by this particular combination of conditions.

PRI: The proportional reduction in inconsistency score determines the level to which the combination of conditions reduces the inconsistency in the relation between the outcome and the conditions. It distinguishes between the cases where the conditions lead to the outcome versus the cases in which it doesn't. Therefore, a high PRI score indicates that the configuration is more consistent with the presence of the outcome than its absence.

Boolean algebra-based set operations are used to evaluate the relationship between the conditions and the result. The intersection of two sets is denoted by the logical operator AND, sometimes referred to as a logical conjunction. The union of the sets is referred to as logical OR, often called logical disjunction, and the negation or complement of a set is referred to as logical NOT (Mello, 2023).

3.6. Validity and Reliability

The selected cases ensure a diverse sample making it feasible to generalise the results to other similar contexts enhancing the external validity. Moreover, the framework facilitates the identification of patterns that are not just unique to India but also other comparative contexts. Further, the reliability of the study is ensured by maintaining a systematic and replicable process of data calibration.

The primary rationale for utilizing fs/QCA in this study has been to improve the validity, robustness, and reliability of the results. The tools to methodically explore configurations of causal conditions that enhance the adoption of EVs by consumers and producers are provided by the QCA technique. The transparency rendered by QCA to the analytical processes such as coding and justification of decisions substantiates this framework more than that of a case-study research. This opens up the process and findings for validation or falsification and adds to its scientific rigor (Berg-Schlosser & Meur, 2009). Moreover, QCA enables an understanding of the complexity of each case (Rihoux & Ragin, 2009) and goes beyond simplistic, probabilistic causal reasoning. Rather than assuming that a single variable causes an incremental effect homogeneously across all cases, this technique facilitates the identification of multiple pathways leading to high EV adoption.

However, the study also attempts to address certain limitations. Firstly, access to uniform data across cases has been limited. The study relied on literature to complement and justify the calibration to mitigate the constraint of lack of baseline data for the identified conditions. Secondly, the conditions' calibration and the qualitative data's quantification allow for subjectivity. To limit the possibility of errancy, the membership functions and justification of set thresholds have been informed in this study, allowing other researchers to review and explore the calibration procedures. Finally, the conclusions drawn from the analysis depend on the conditions and cases included in the study and do not imply that these are the only 'true causal ingredients'. It has tried to achieve maximum heterogeneity with the included cases and conditions are based on theoretical relevance. Moreover, the final set of conditions was a result of a back-and-forth iterative process.

The data has been retrieved from official Government of India databases and policy gazettes. To triangulate, the used data has also been cross-referenced with industry reports and academic papers.

4. Results, analysis and discussion

"When regional assets are leveraged to draft policy frameworks to drive both the demand and supply of electric vehicles, a comprehensive transition to sustainable mobility is ensured."

This section presents the interpretation of the necessary conditions, truth table, minimized solutions, and the key findings resulting from the fs/QCA. As QCA is an iterative process, multiple iterations were tested with different combinations of conditions and calibrations. The results presented below are a selection of the most apt conditions and calibrations that are also justified by the literature. The results identify the conditions or configurations that are conducive to the widespread adoption of BEVs.

4.1. Demand Side

Based on the calibration rules mentioned in Tables 3.2 and 3.3, the raw data (refer to Appendix 2) calibrated in R produces the following data table which is used for further analysis.

State	EV Penetration	FI	NFI	PI	PCS
Andaman & Nicobar Island	0.00	0.98	0	0.87	0.00
Andhra Pradesh	0.05	0.03	1	0.71	0.52
Arunachal Pradesh	0.00	0.51	0	0.45	0.00
Assam	0.99	0.39	1	0.03	0.05
Bihar	0.81	0.21	1	0.00	0.11
Chandigarh	1.00	0.40	1	1.00	1.00
Chhattisgarh	0.88	0.59	1	0.05	0.05
Delhi	1.00	0.40	1	1.00	1.00
Goa	1.00	0.57	1	1.00	1.00
Gujarat	0.29	0.97	0	0.96	0.57
Haryana	0.06	0.14	1	1.00	0.97
Himachal Pradesh	0.00	0.03	1	0.76	0.02
Jharkhand	0.06	0.97	1	0.01	0.35
Karnataka	0.98	0.03	0	1.00	1.00
Kerala	0.99	0.04	1	0.91	1.00
Madhya Pradesh	0.21	0.03	1	0.06	0.05
Maharashtra	0.93	0.97	1	0.62	0.98
Manipur	0.00	0.03	0	0.01	0.01
Meghalaya	0.00	1.00	0	0.02	0.03
Odisha	0.65	0.96	1	0.08	0.09
Punjab	0.08	0.05	1	0.24	0.66
Rajasthan	0.80	0.64	1	0.11	0.18
Tamil Nadu	0.26	0.85	0	1.00	0.83
Uttar Pradesh	0.96	0.96	1	0.01	0.57
Uttarakhand	0.74	0.06	1	0.91	0.16
West Bengal	0.00	0.87	0	0.06	0.71

Table 4.1: Calibrated demand-side data

4.1.1. Testing for necessity

Before testing for sufficiency, the first step involves testing for necessary conditions for the expected outcome. A necessary condition is one without the presence of which the outcome cannot occur (Mello, 2023). This means that the outcome of EV penetration is a subset of the necessary conditions.

	inclN	covN	RoN
FI	0.522	0.524	0.688
NFI	0.880	0.623	0.541
PCS	0.625	0.668	0.781
Per Capita Income	0.576	0.570	0.704
~ FI	0.564	0.540	0.674
~ NFI	0.120	0.191	0.736
~ PCS	0.484	0.438	0.601
~ Per Capita Income	0.476	0.462	0.646

Table 4.2: Test for Necessity (demand-side)

The individual conditions do not display a consistency score of 0.9 or more to argue for a necessary relationship. In cases of complex phenomena like EV, often multiple conditions either in conjunction or disjunction becomes necessary. Therefore, the conditions were tested for necessary conjunctions or disjunctions that again showed the trivialness of these conditions (Refer to Appendix 4).

4.1.2. Truth Table Analysis

The assessment of the demand-side conditions suggests multiple pathways leading to high EV adoption. These pathways define the different combinations of conditions that are sufficient for the outcome - EV penetration.

FI	NFI	PCS	PI	OUT	n	incl	PRI	Cases
1	1	1	1	1	2	0.96	0.95	Goa, Maharashtra
0	0	1	1	1	1	0.94	0.93	Karnataka
1	1	1	0	1	1	0.85	0.75	Uttar Pradesh
1	1	0	0	0	4	0.78	0.69	Chhattisgarh, Jharkhand, Odisha, Rajasthan
0	1	1	1	0	5	0.69	0.64	Andhra Pradesh, Chandigarh, Delhi, Haryana, Kerala
0	1	0	0	0	3	0.65	0.53	Assam, Bihar, Madhya Pradesh
0	1	1	0	0	1	0.51	0.13	Punjab
0	1	0	1	0	2	0.46	0.26	Himachal Pradesh, Uttarakhand
1	0	1	1	0	2	0.38	0.01	Gujarat, Tamil Nadu
1	0	0	1	0	1	0.23	0.00	Andaman & Nicobar Island
1	0	1	0	0	1	0.05	0.00	West Bengal

0	0	0	0	0	1	0.02	0.00	Manipur
1	0	0	0	0	2	0.02	0.00	Arunachal Pradesh, Meghalaya
0	0	0	1	?	0	-	-	
0	0	1	0	?	0	-	-	
1	1	0	1	?	0	-	-	

Table 4.3: Demand-side truth table

Note: The symbol <?> denotes logical remainders

The truth table does not display counter-intuitive rows where all positive conditions lead to a negative outcome and vice versa or any logical contradictions. There are three ‘logical remainders’ or causal pathways that are not covered by the empirical data as illustrated by the truth table. This is also known as the ‘limited diversity problem’ which indicates that there are possibly more logical configurations than the number of cases from empirical observation (Schlosser & Meur, 2009).

The truth table suggests that Goa, Maharashtra, Karnataka, and Uttar Pradesh are cases with high consistency and PRI score which implies a strong causal relationship between the conditions and the outcome. Rows 1, 2, and 3, with high inclusion and PRI scores, indicate a strong and consistent causal relation between the outcome and the conditions. All configurations that exhibit the outcome display a consistency of over 0.8.

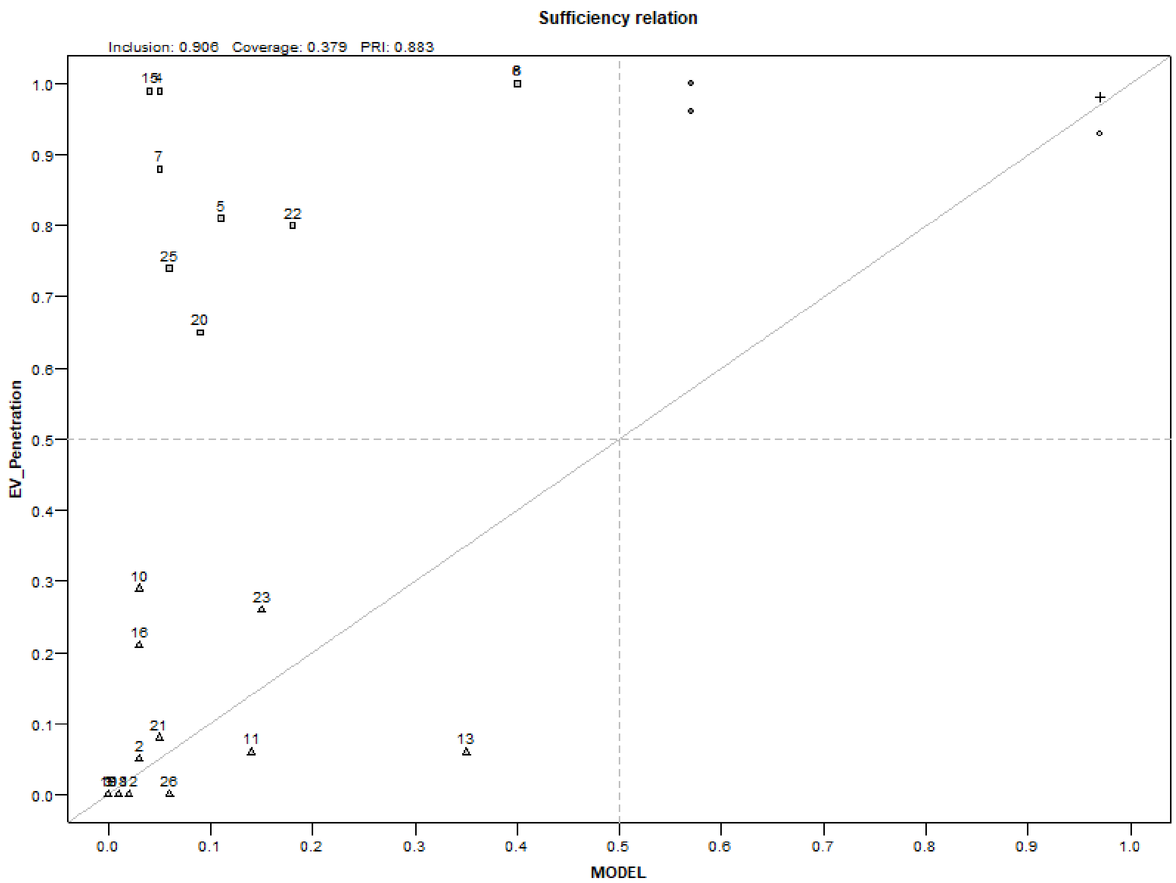
These primitive expressions are then minimized to derive the prime implicants. The models derived from the truth table emphasize the configurations which are sufficient for the outcome.

4.1.3. Minimization Results

The construction of the truth table is followed by ‘logical minimization’, where the R software used for fs/QCA applies Boolean algebra to *“identify combinations of conditions that are sufficient for the outcome”* (Ter Horst, 2015, pg. 63). This section answers sub-question 1 by identifying pathways that increase EV demand and adoption by consumers.

Based on prevailing theories (see Chapter 2), all the conditions included in this demand-side study – financial incentives (FI), non-financial incentives (NFI), public charging stations (PCS), and personal income (PI) – are hypothesized to positively contribute to the attainment of high EV penetration. During the minimization procedure, this postulation is articulated for identifying the intermediate solutions, and therefore, the analysis includes all the logical remainders.

M1: ***FI*NFI*PCS*** + ***~FI*~NFI*PCS*PI*** → *EV_Penetration*



Graph 4.1: X-Y plot for the sufficiency relation of demand-side calibration

The majority of points are found in the upper-left section, indicating sufficiency, as shown in Graph 4.1. This is established by the comparatively high inclusion score of 0.906 and a similar PRI score of 0.883, which both confirm the fact that M1 is indeed linked to high EV adoption. The low coverage score is addressed in Section 4.3.

	incl	***PRI***	***covS***	***covU***	***Cases***
*FI*NFI*PCS*	*0.895*	*0.868*	*0.289*	*0.289*	*Uttar Pradesh, Goa, Maharashtra*
~FI~NFI*PCS*PI*	*0.943*	*0.931*	*0.090*	*0.900*	*Karnataka*
M1	*0.906*	*0.883*	*0.379*		

Table 4.4: Demand-side solutions

Note: "In Boolean notation, multiplication (*) indicates logical 'AND', addition (+) represents logical 'OR', and (→) indicates sufficient conjunctions" (Ter Horst, 2015, pg. 66).

These results suggest that the conditions are not sufficient individually for higher EV penetration, instead a combination of them is. The conditions included in the intermediate solutions are the superset of the conservative solution paths and highlight the core conditions.

1) The first pathway that leads to higher adoption of EVs over ICEVs is a ***'Comprehensive Incentives and Infrastructure' pathway*** denoted as *FI*NFI*PCS*. The conjunction of robust financial incentives, comprehensive non-financial incentives, and extensive charging infrastructure is sufficient for widespread EV adoption by consumers. It suggests

that states with higher per capita income that provide significant fiscal and non-fiscal incentives lead to higher EV penetration. This configuration encompasses 3 cases namely Uttar Pradesh, Maharashtra, and Goa. Delving deeper into these individual cases:
As per the Government of Maharashtra & Environment and Climate Change Department, (2021), **Maharashtra** offers a subsidy amount of up to Rs. 10,000 for 2-W, Rs. 30,000 for 3-W, and Rs. 1,50,000 for cars with a minimum amount of Rs. 5000 per kWh for these vehicles. For the first 1000 e-buses, the state provides a 10% subsidy on the vehicle cost capping at Rs. 20,00,000. Moreover, to phase out ICEVs, the state offers incentives up to Rs. 7000 for 2-W, Rs. 15,000 for 3-W, and Rs. 25,000 for 4-W on the disposal of unfit ICEVs. Maharashtra provides interest subvention on loans for purchasing EVs, in addition to registration fees and road tax exemption. The state has 3083 PCS indicating that there are around 10 PCS every 1000 square kilometres and an individual earns an average annual income of Rs. 2,15,233. The policy also encourages ULBs to provide property tax refunds to residential owners who install private charging stations. The creation of PCS every 25 km on highways and having 20% of total parking space to be an EV-ready parking option in new residential buildings is mandated (Government of Maharashtra & Environment and Climate Change Department, 2021).
Uttar Pradesh has outlined objectives to facilitate the transition to an eco-friendly transport network in cities (BEE, 2022). As per the Uttar Pradesh Government (2022), the purchase subsidy for 2-wheelers is limited to Rs. 5,000 per vehicle, Rs. 12,000 for 3-W, Rs. 100,000 for 4-W and Rs. 20,00,000 for e-buses. Further, it provides scrapping incentives of Rs. 5000 for 2-wheelers and Rs. 10,000 for 3 and 4-wheelers. The state has 583 PCS indicating that there are around 3 PCS every 1000 sq. km and an individual earns an average annual income of Rs. 83,565. Moreover, the state promotes the development of charging infrastructure in all public parking lots, bus terminals, metro stations, gas pumps, government and corporate, residences, educational and health institutions, commercial locations, etc. (Uttar Pradesh Government, 2022).
Goa uniquely has set dynamic incentive rates that keep decreasing every financial year until the policy expires. As per the Government of Goa (2021), for 2-W, the purchase subsidy is capped at Rs. 30,000 per vehicle, at Rs. 60,000 for 3-W and Rs. 300,000 for 4-W. The state also provides scrapping incentives of Rs. 5000 for 2-wheelers and Rs. 10,000 for 3 and 4-wheelers. The state has 113 PCS indicating that there are around 30 PCS every 1000 sq. km and an individual earns an average annual income of Rs. 4,72,070. The government requires charging stations to be located every 3 km in cities and every 25 km on highways. All new and renovated residential and non-residential buildings and group housing societies must have at least 20% e-car spots with necessary conduits. The state also installs charging stations in the international airport, selected transport corporation bus depots, and government complexes.

2) With high coverage and consistency scores implying a greater extent to which the case is consistent with the outcome, the alternative ***'Affluence-driven Infrastructure' pathway*** suggests a *~FI*~NFI*PCS*PI* configuration as uniquely observed in the case of **Karnataka**. The conjunction of no robust financial incentives, no comprehensive non-financial incentives but extensive charging infrastructure, and individuals with purchasing power is sufficient for widespread EV adoption by consumers. With a high unique coverage score, this configuration covers a significant portion of the outcome that is not explained by other solutions. With a high consistency and PRI score, this configuration is consistent and has a high power in explaining the outcome. This pathway suggests that EV penetration in states that do not have very significant fiscal and non-financial incentives is driven by higher per capita income. This means that a wealthier population with sufficient purchasing power and access to charging infrastructure that improves user

comfort does not rely on other incentives to transition to EVs. As education and income are correlated, high income or higher literacy is related to increased awareness and openness to adopt new technologies. Leveraging this demand driven by heightened awareness and willingness of people to experiment in cities like Bangalore, initiates a huge market potential for EVs in Karnataka. The state has 5130 PCS indicating that there are around 27 PCS every 1000 sq. km and an individual earns an average annual income of Rs. 3,01,673. Further, the government mandated charging infrastructure in all multistorey buildings, apartments, and tech parks and encouraged apartment associations to provide dedicated charging stations. Moreover, Transport Corporations and Municipal Corporations are mandated to provide charging stations for e-2Ws at transit depots to encourage last-mile commutes (Rather et al., 2021).

4.2. Supply Side

Based on the calibration rules mentioned in Tables 3.4 and 3.5, the raw data (refer to Appendix 3) calibrated in R produces the following data table that is used for further analysis.

State	EV_Deployment	Supply_FI	Supply_NFI	GDP	Industry
Andaman & Nicobar Island	0.01	0.05	0	0.94	0
Andhra Pradesh	0.45	1.00	0	0.74	1
Arunachal Pradesh	0.01	1.00	0	0.63	0
Assam	0.86	0.95	1	0.07	0
Bihar	0.97	0.49	0	0.00	0
Chandigarh	0.03	0.49	1	1.00	0
Chhattisgarh	0.39	1.00	1	0.20	0
Delhi	0.99	0.00	1	1.00	0
Goa	0.03	1.00	1	1.00	0
Gujarat	0.92	0.49	0	0.96	0
Haryana	0.52	0.94	1	0.97	0
Himachal Pradesh	0.02	0.00	1	0.91	0
Jharkhand	0.15	0.14	0	0.02	0
Karnataka	1.00	1.00	0	0.97	1
Kerala	0.78	0.67	0	0.00	0
Madhya Pradesh	0.78	0.49	0	0.05	0
Maharashtra	1.00	0.49	1	0.00	0
Manipur	0.02	0.00	1	0.01	0
Meghalaya	0.01	0.00	1	0.05	0
Odisha	0.53	0.95	1	0.26	0
Punjab	0.15	0.00	0	0.74	0
Rajasthan	0.98	0.05	1	0.24	1
Tamil Nadu	0.96	0.99	0	0.95	1
Uttar Pradesh	1.00	0.85	0	0.01	0
Uttarakhand	0.23	0.09	0	0.93	0
West Bengal	0.46	0.00	1	0.11	0

Table 4.5: Calibrated supply-side data

4.2.1. Testing for necessity

As discussed in sub-chapter 3.5, a necessary condition is one without the presence of which the outcome cannot occur (Mello, 2023). This signifies that the outcome of EV adoption is a subset of the necessary conditions.

	inclN	covN	RoN
FI	0.646	0.656	0.738
NFI	0.443	0.456	0.648
EV Industry	0.250	0.838	0.971
GDP	0.478	0.501	0.675
~ FI	0.436	0.455	0.653
~ NFI	0.557	0.573	0.701
~ EV Industry	0.750	0.456	0.250
~ GDP	0.633	0.640	0.728

Table 4.6: Test for Necessity (supply-side)

The individual conditions do not display a consistency score of 0.8 or more to argue for a necessary relationship. Therefore, the conditions were tested for necessary conjunctions or disjunctions that again showed the trivialness of these conditions (refer to Appendix 5).

4.2.2. Truth Table Analysis

The assessment of the supply-side conditions suggests multiple pathways leading to high EV adoption. These pathways define the different combinations of conditions that are sufficient for the outcome- EV deployment. The supply-side factors focus more on manufacturing, R&D, and infrastructural development.

FI	NFI	PCS	Industry	OUT	n	incl	PRI	Cases
0	1	1	0	1	1	1	1	Rajasthan
1	0	1	1	1	3	0.89	0.86	Andhra Pradesh, Karnataka, Tamil Nadu
1	0	0	0	1	2	0.87	0.83	Kerala, Uttar Pradesh
1	1	0	0	0	3	0.79	0.70	Assam, Chhattisgarh, Odisha
0	0	0	0	0	1	0.73	0.55	Jharkhand
1	0	0	1	0	1	0.51	0.38	Arunachal Pradesh
0	1	0	1	0	2	0.49	0.41	Delhi, Himachal Pradesh
1	1	0	1	0	2	0.37	0.04	Goa, Haryana
0	0	0	1	0	3	0.36	0.17	Andaman & Nicobar Island, Punjab, Uttarakhand
0	1	0	0	0	3	0.32	0.18	Manipur, Meghalaya, West Bengal
1	1	1	0	?	0	-	-	
1	1	1	1	?	0	-	-	

0	0	1	0	?	0	-	-	
0	0	1	1	?	0	-	-	
1	0	1	0	?	0	-	-	
0	1	1	1	?	0	-	-	

Table 4.7: Supply-side truth table

Note: The symbol <?> denotes logical remainders

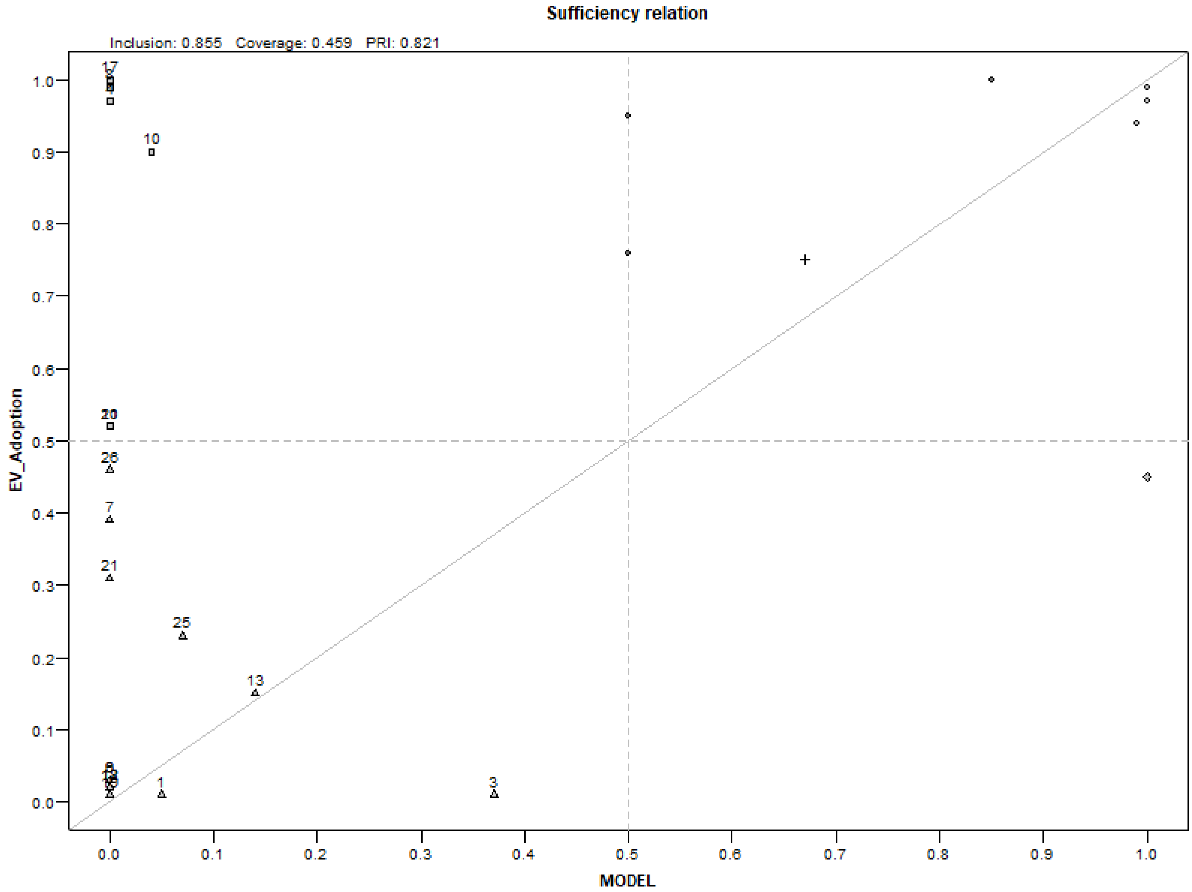
The truth table does not display contradictory or counter-intuitive rows where all positive conditions lead to a negative outcome and vice versa, or any logical contradictions. It demonstrates that six causal pathways are not covered by the empirical data leaving logical remainders. The model derived from the truth table emphasizes the causal conditions that are sufficient for the outcome. The high consistency and PRI scores of the rows with positive outcomes suggest pathways with a strong and causal relation.

4.2.3. Minimization Results

The construction of the truth table is followed by 'logical minimization', where the R software used for fs/QCA applies Boolean algebra to determine which configurations are sufficient for the outcome. This section answers sub-question 2 by identifying pathways that increase EV adoption by strengthening the supply side.

Based on prevailing theories (see Chapter 2), all the conditions included in this supply-side study – financial incentives (FI), non-financial incentives (NFI), the presence of the EV industry (Industry), and the regional gross domestic product (GDP) – are hypothesized to positively contribute to the attainment of high EV penetration. During the minimization procedure, this postulation is articulated for identifying the intermediate solutions, and therefore, this analysis includes all logical remainders.

M1: FI*Industry + NFI*Industry + FI*~NFI*~GDP → EV Adoption



Graph 4.2: X-Y plot for the sufficiency relation of supply-side calibration

The majority of points are found in the upper-left section, indicating sufficiency, as shown in Graph 4.2. This is established by the comparatively high inclusion score of 0.855 and a similar PRI score of 0.821, which both confirm the fact that M1 is indeed linked to high EV adoption. The low coverage score is addressed in Section 4.3.

	inclS	***PRI***	***covS***	***covU***	***Cases***
*Supply_FI*EV_Industry*	0.799	0.755	0.182	0.152	*Andhra Pradesh, Karnataka, Tamil Nadu*
*Supply_NFI*EV_Industry*	0.970	0.969	0.072	0.069	*Rajasthan*
Supply_FI~Supply_NFI*~GDP*	0.887	0.833	0.234	0.209	*Kerala, Uttar Pradesh,*
M1	0.855	0.821	0.459		

Table 4.8: Supply-side solutions

Note: "In Boolean notation, multiplication (*) indicates logical 'AND', addition (+) represents logical 'OR', and (→) indicates sufficient conjunctions" (Ter Horst, 2015, pg. 66).

(1) The ***'Industry-driven Financial Incentive' pathway*** denoted by the configuration *Supply_FI*EV_Industry* is observed in Andhra Pradesh, Karnataka, and Tamil Nadu.

Andhra Pradesh lays significant emphasis on R&D through a Rs 500 crores research grant for funding ground-breaking mobility solutions and financial assistance for patent registration and quality certification (Padhke et al., 2022). While the state does not provide any demand-side financial incentives, it provides incentives for setting up charging or swapping infrastructure in existing malls and commercial buildings with a subsidy of 25% of fixed capital investment and complete reimbursement of SGST for battery swapping stations.

Karnataka emphasizes the creation of units for the implementation and supervision of research and infrastructure. The 'Karnataka Electric Mobility Research & Innovation Centre' was formed for research activities and the 'Special Purpose Vehicle' (SPV) monitors the establishment of charging infrastructure in Bengaluru. Karnataka has set a specific target to create a conducive environment shifting from ICEVs to EVs. It aims to bring Rs 31,000 crore in investments and provide 55,000 people with work opportunities on both the supply and demand sides (TERI, 2021). The state provides incentives to set up charging stations and a stipend for in-plant training. It lays special emphasis on research and development by creating working groups that develop technology for battery, charging infrastructure, and network integration. Moreover, a Venture Capital Fund was set up for research activities in EVs and Start-up incubation centers to facilitate EV sector development. The transparent bidding process for setting up fast charging and battery swapping stations on State-owned lands and zero wheeling charges for EV charging stations further attract investments here.

According to the Government of Tamil Nadu (2023), **Tamil Nadu** also has ambitious goals to become the go-to state in Southeast Asia for EV manufacturing. To create a circular economy in the state, it seeks to advance innovations and R&D in the automotive and shared mobility sectors as well as the recycling sector. To incentivize charging during non-peak hours, the state reduces energy charges by 50% and a 75% reduction in demand charges. Further, the state has launched the Green tariff which is based on renewable energy. To foster an ecosystem, the State aims to develop associations between industry, academia, and start-ups, in the field of R&D. In partnership with industries, research programs are launched in technical institutes and research facilities in fields like batteries, powertrains, motors/controllers, and battery management systems. Several university-based EV incubation centers are currently operating in Tamil Nadu following the government's efforts to expand the number of incubation centers for EV start-ups. These centers offer incubation services like offices, shared amenities, and mentoring support. To invest in start-ups in the sunrise sectors, the Tamil Nadu Infrastructure Fund Management Corporation Limited created the Tamil Nadu Emerging Sector Seed Fund. The State Government offers start-ups the required handholding services through the Tamil Nadu Start-Up and Innovation Mission (TANSIM). Under the Tamil Nadu Industrial Policy 2021, a Research & Technology Fund has been set up with a corpus of Rs.100 crores, that invites proposals for R&D in EV. The State conducts a demand assessment to ascertain its peak electricity requirements. Accordingly, it is recommended that EV charging service providers install their own renewable energy generating stations on their property so that EVs can be charged. All these initiatives are also supported by the well-established Automobile & Auto-components industry in the State.

(2) The causal recipe ***'Industry-driven Non-Financial Incentive' pathway*** denoted by *Supply_NFI*EV_Industry* is observed in the case of **Rajasthan**. The state takes a step further and amends building bylaws to include provision for EV charging infrastructure and is also working on mobile applications for PCS. Rajasthan provides land at a 50% concessional rate to set up charging stations. The private enterprises are provided with SGST reimbursement for the procurement of EV fast chargers and the first 100 public fast

PCS or swapping stations are reimbursed for the cost of upstream infrastructure (up to Rs. 5 lakhs per PCS). Utilizing existing electricity connections, the government mandates setting up charging points at offices and residences and also allows power purchase for these charging stations through open access. The state's objectives also outline the need for a network of EV charging stations and battery swapping stations for all EV categories, focusing on clean energy sources. The presence of a strong automobile and EV industry aligns with the goals to promote the manufacturing of EVs and batteries in the state. Further, the state focuses on capacity building to increase EV awareness and has launched a 'Centre of Excellence' for advanced electric and automotive research (Transport and Road Safety Department, 2022).

(3) The other configuration with a high coverage and consistency rate is the ***'Economically Constrained Incentive' pathway*** denoted by *Supply_FI*~Supply_NFI*~GDP* as observed in **Kerala and Uttar Pradesh**. This indicates that high supply-side financial incentives, relatively lower non-fiscal incentives, and low GDP are sufficient for high EV adoption. All these states outline policies for R&D through setting up a research cell or collaborating with universities, introducing or updating EV curriculums in universities, capacity building, incubation centers, etc.

Kerala has set clear objectives focusing on promoting shared mobility and establishing an ecosystem for in-state EV component manufacturing. The state provides a 25% capital subsidy for charging and battery swapping stations along with incentives to put up charging stations in existing malls, and private and commercial constructions. KSRTC is mandated to set up charging stations at bus depots and oil marketing companies and energy operators are permitted to set up PCS and Bulk charging stations (BCS) on their own (Transport Department, 2019).

With similar EV objectives as Andhra Pradesh, **Uttar Pradesh** intends to become a global center for EV research and production by enabling investments for developing charging infrastructure and attracting manufacturers to set up their units in the state and expand supply to a global market. The state does not provide any non-fiscal incentives. Charging and swapping stations are provided with a one-time capital subsidy at the rate of 20% and a skill development incentive for employees in all defined manufacturing projects. Further, the responsibility for parking reform policies in cities to develop public charging and swapping stations in parking spaces has been assigned to the Urban Local Bodies. In addition to implementing the EV tariff, the Energy Department (DISCOMs) guarantees expedited electricity connections to EV battery service providers. With participation from DISCOMs, the Chief Town & Country Planner (CTCP), the housing, transportation, and industry departments, as well as other pertinent government agencies and local bodies, the State formed a "Working Group on Fast Track Development of Charging Infrastructure" under the Urban Development Department. This group permits open access to charging stations or swapping kiosks (Uttar Pradesh Government, 2022).

4.3. Interpretation of the results

Summarising the conditions and pathways discussed above -

Demand-Side Conditions:

- PCS is present in both the solutions explaining EV adoption.
- Different levels of financial and non-fiscal incentives explain high EV penetration depending on how they are combined with other conditions.
- States with low financial and non-financial incentives emphasize high individual income for a high outcome.

Supply-Side Conditions:

- The presence of a strong EV industry has been observed in 2 out of 3 solutions explaining high EV adoption.
- Similarly, the presence of significant financial incentives has also been observed in 2 out of 3 solutions explaining high EV adoption.
- Non-fiscal incentives are either negated or positive to explain high EV adoption conditional to how it is combined with other conditions.

As discussed in section 4.2, it is evident from the results that Uttar Pradesh, Goa, Maharashtra, and Karnataka are accelerating EV by strengthening demand or consumer side conditions. Kerala, Andhra Pradesh, Uttar Pradesh, Karnataka, Tamil Nadu, and Rajasthan are accelerating EV growth by strengthening supply or innovation side conditions. It is interesting to note that Karnataka and Uttar Pradesh have comprehensive strategies that influence both consumers and producers to drive EV adoption.

The major configurations explaining the outcome of EV adoption through demand conditions are *Comprehensive Incentives and Infrastructure* and *Affluence-Driven Infrastructure* Pathways. The effectiveness of the former pathway suggests that states that invest in financial and non-financial incentives while also building robust charging infrastructure, create a conducive environment for consumers to transition to EVs. This is also along the lines of policy mixes which proposes that multi-faceted incentives are more likely to counter the barriers to EV adoption. While Goa opts for dynamic incentives, Maharashtra emphasizes phasing out ICEVs. While the broader policy strategy proves to be effective, this diversity also underscores the importance of flexibility in policy-making. Uttar Pradesh has a lower GDP compared to the other states demonstrating this pathway, suggesting that comprehensive policies help mitigate economic disadvantages. The latter pathway suggests that consumer behavior is determined by the availability of infrastructure and the ability to afford the upfront purchase costs. In wealthier states, the convenience of an extensive charging network and high income which also correlates to high education and awareness compensates for the lack of comprehensive policies. The former pathway suggests a combination of conditions that lead to the expected outcome while the latter suggests an alternate pathway to achieve the outcome when certain conditions are absent. Consumer demand is mostly driven by user comfort. The condition was deemed ‘not necessary’ even though the presence of public charging stations was found in both solution terms that were sufficient for the outcome. Maharashtra and Karnataka, home to major cities like Mumbai and Bangalore, attract a high-skilled labor pool. The employment opportunities generated here further increase the demand for everyday commutes making it a major consumer market. Uttar Pradesh, Goa, and Maharashtra also have strong tourism industries and as studies suggest, it provides an entry point for electric micromobility.

The southern states in India are leading in EV production and innovation. The major configurations explaining the outcome of EV deployment through supply conditions are *Industry-Driven Financial Incentive*, *Industry-Driven Non-Financial Incentive,* and *Economically Constrained Incentive* Pathways. The industry-driven incentive pathways underscore the synergy between government initiatives and industry collaborations. These states have clearly defined objectives to improve manufacturing and innovation and build an ecosystem fostering local EV production and adoption. The pathways suggest that incentives or measures that directly target the EV industry players are more likely to push deployment owing to an established ecosystem within the state. Tamil Nadu and Rajasthan have well-established EV, Automobile & Auto-components and Renewable Energy industries that work together towards a common objective. Similarly, Andhra Pradesh has Renewable Energy, Automobiles & EVs, and Infrastructure & Urban Development industries, addressing all stages of the EV lifecycle. Home to the Silicon Valley of India, Karnataka, apart from an EV and Automobile & Auto-components industry, also has a major Innovation & Start-Up industry. This helps bring investment in innovation and R&D. These states had well-established automobile sectors, the introduction of the EV sector and using incentives to push the traditional car manufacturers towards EV has been essential in fighting the incumbent industry. The Tourism sector in Kerala and the Tourism and Renewable Energy sectors in Uttar Pradesh also foster cross-sectoral collaboration and partnerships, easing the adoption of EVs. Here, industries also collaborate with educational institutions and provide in-plant training and capacity building and the curriculum has been updated to include EV in technical schools. Or an alternate pathway that improves adoption especially in states with lower GDP and not sufficient non-fiscal incentives but through the provision of sufficient financial incentives. A lower GDP suggests that the regions do not have enough financial backing to deal with the failure of this transition. Therefore in such cases, significant financial incentives provide better resources for industries to invest in or transition towards electric mobility. All these states have made major investments in R&D through research grants, setting up of governing bodies, providing and incentivizing in-plant training, and strong policy instruments encouraging the setting up of charging infrastructures. The provision of monetary support and investing in research and innovation in EV technology also instills confidence in the users regarding the benefits of EV and the presence of supporting infrastructure creates a suitable EV ecosystem in the state.

The observed conditions are the INUS conditions ("Insufficient but Necessary part of a condition which is itself Unnecessary but Sufficient for the result") which are not sufficient or necessary by themselves but are part of a group of conditions that are necessary for the outcome (Legewie, 2013). Whenever these configurations are present, so is the outcome. But this does not imply that the absence of these is sufficient for a non-outcome.

In this QCA analysis of EV adoption across 26 states in India, a low raw solution coverage is observed. As evidenced by the clustering of cases above the 0.0 to 0.3 range on the x-axis in graphs 4.1 and 4.2, it is evident that some cases do not align with the identified solution pathways. Given the limited number of cases explained by the model, it can be inferred that the theoretical conditions may not be completely relevant in set-theoretic terms. Although the coverage score is low, which in this study can be attributed to omitted variables, it does not undermine the validity of the inferences. As demonstrated by Baumgartner and Thiem (2017, pp. 16-18, tests IIa and IIb), given that the omitted variables do not share causal paths with the conditions included in the study, it is possible to make accurate inferences despite low coverage. In this analysis, the omitted variables, such as private sector investments, road quality, presence of maintenance services, etc. are deemed to not share causal paths with the conditions of policy incentives, GDP, per capita income, presence of an EV industry, and extensive charging network. The lower coverage thus reflects the complexity of the phenomenon and the limited scope of the included conditions. This limitation is factored into the interpretation of the findings.

Finally, the results validate the configurational approach and the concept of policy mixes ensuring that it is not just individual policies, but instead a combination of mutually reinforcing policies that are tailored to the regional factors which increase the uptake of electric mobility. The pathways also suggest an interdependence between policies where the effectiveness of one policy can be determined by the presence or absence of another. For example, non-financial incentives are more effective in regions with an EV industry or the ones with investments in infrastructure. Investment in infrastructure might not yield results without financial or industry incentives.

5. Conclusions

"The growth of EV hinges on a balance between demand stimulation and supply readiness, that demands comprehensive policy frameworks addressing both of these dimensions."

5.1. Main Findings

This study aimed to identify pathways of policy conditions and regional assets that lead to high adoption and deployment of electric vehicles in the Indian states. The study was primarily guided by the question: *Which combinations of state-level EV policies and local assets are sufficient for the high adoption of electric vehicles (EVs) in Indian states?* A holistic review of previous studies to answer this question, led to the following findings:

- Transition from ICEVs to EVs is a complex phenomenon, requiring a holistic approach addressing various components of the ecosystem and not individual instruments (Berkeley et al., 2018).
- EV transition is supported by a variety of supply and demand-side policy interventions (Lopez-Behar et al., 2019, as cited in Brand et al., 2013, Wolinetz and Axsen, 2017).
- The effectiveness of these policy interventions is influenced by the regional assets (Kester et al., 2018).

Hence, the main question is answered by breaking it down into the following sub-questions -

(1) Which pathways lead to high EV penetration in the consumer market?

(2) Which configurations of supply-side conditions are sufficient for high EV adoption?

(3) What are the identified patterns between the states with high EV adoption reinforced through demand versus supply side factors?

With an analysis guided by QCA on 26 Indian states, the study identifies the configurations of regional assets and policy conditions that propel EV adoption. Two QCAs were conducted to determine sufficient conditions explaining the outcome from both demand and supply perspectives. Further, the role of regional assets in determining the course of policy interventions in enhancing EV adoption is highlighted.

The results suggest two causal recipes for high EV adoption among consumers through demand-side conditions and three causal recipes for high EV deployment by industries through supply-side conditions. In line with the configurational approach and policy mixes, the study posits that high EV penetration and deployment are not driven by an individual condition but by a combination of policy conditions that combine with the regional assets to direct the EV outcome. It is observed that this phenomenon is unique to each context and based on the regional assets of the individual states, either demand or supply-side policy frameworks drive EV uptake. While the study did not identify any necessary conditions, a few configurations were proved to be sufficient for the outcome.

In response to the first sub-question, EV adoption among consumers is driven by the financial and non-financial incentives offered to users in conjunction with an adequate network of public charging stations. The financial incentives offered decrease the upfront purchase expenses of these vehicles which makes them more affordable to the general masses. Moreover, the network of charging stations mandated in both public and private land, improves user comfort making EV use more feasible. Alternatively, lower amounts of financial incentives and less comprehensive non-financial incentives in conjunction with a network of public charging stations and high personal income increase the uptake of EVs. A higher personal income is correlated to higher literacy, suggesting more environmental awareness that leads to openness to adoption and ease of EV purchase and maintenance. The presence of a charging network is crucial suggesting that accessibility and convenience drive consumer behavior. Regions with an affluent population, indicating higher EV awareness and purchasing power, do not rely on policy incentives but on infrastructural developments. While high-income states need to strengthen the public charging network, the other states also need comprehensive policies providing financial and non-financial incentives to stimulate user demand.

In response to the second sub-question, the two effective pathways to high EV adoption are a 'Sector-Specific Incentive Pathway' and an 'Economically Constrained Incentive Pathway'. The financial incentives offered to market actors in conjunction with the presence of a well-established EV industry and the conjunction of non-financial incentives and the EV industry are sufficient for high EV deployment. A thriving automobile and EV sector can facilitate the deployment of EVs. Alternatively, states with lower GDP and non-comprehensive non-financial resources but high financial incentives offered to institutions and industries for manufacturing and innovation in the field of EV display high EV deployment. A positive effect is seen on the supply side when the state focuses on R&D and innovations. The supply-side incentives to generate employment and attract investments. This ensures that the EV ecosystem for production and adoption is established and sustainable in the long run. As suggested by the research framework, it is evident that EV uptake is not determined by individual factors but by a combination of them that work together with local assets. Moreover, the policy initiatives work differently to increase the demand versus supply of EVs. The role of policy initiatives through incentives varies depending on the contextual factors for both demand and supply. The presence of certain local conditions compensates for the lack of robust policy incentives as seen in the case of Karnataka. It also pushes for the need for strengthening certain policy frameworks for example in Kerala and Uttar Pradesh. It is evident from the analysis that public charging stations are crucial to increasing the demand and attracting users towards EVs. The role of relevant industries and financial investments in R&D and policy mandates for charging infrastructure is crucial from a supply perspective for a shift towards EVs.

In response to the third sub-question, the role of industries is critical in ensuring EV growth. All southern states are leading in EV adoption through strong supply-focused interventions. States with established EV or automobile industries are better positioned to leverage supply-side incentives with their strong base in manufacturing. Moreover, these states also have leading academic institutions that are collaborating for the improvements in R&D. The synergy between government, academia, and industries fosters innovation and advancements in overall EV development. Therefore, in states that already have an established ecosystem, focusing on the supply side yields results. Economies that do not have the ecosystem or financial backing for this transition, rely on increasing adoption by improving consumer interest. The purchase subsidies help tackle the barrier of high TCO by reducing upfront costs. Moreover, states with strong tourism industries show a high penetration in the demand side. The need for sustainable and eco-friendly mobility options especially in touristy destinations, provides an entry point for EVs. These states also provide financial and non-fiscal incentives for consumers.

The use of QCA allowed for the identification of multiple causal pathways and the interaction between policy, infrastructural, and socio-economic conditions. However, it is constrained by the quality and granularity of data available. The pathways only account for the included conditions and not the role of other influencing conditions that are not factored in. Moreover, it was evident that some empirical conditions might not always be relevant in set-theoretic terms. As the study relied on information gathered from policy gazettes, the outcome represents policy intent rather than on-ground implementation. While the insights drawn from this study are valuable, it needs to be adapted as the EV ecosystem evolves.

5.2. Avenues for further research

This thesis adds to the existing studies on EV adoption by determining configurations that are associated with higher EV purchases among consumers and deployment by the industries. Uniquely, the study provides a comprehensive view of factors formulating EV adoption, incorporating demand and supply-side conditions separately. This provides various avenues for further research.

Firstly, the study can be extended to other categories of EVs such as HEVs, PHEVs, etc., and expand the scope to technological attributes and also private sector investments. The findings emphasize the role of EV and tourism sectors in EV uptake. Further studies can delve into the relationship between EV adoption and individual sectors.

Secondly, longitudinal studies are required to analyze how the policy changes over the years affect EV adoption. These studies must examine the post-policy period scenario or the status of EV adoption after the completion of the policy term when the interventions are not just proposals but are on-ground and functioning. This would bridge the gap between policy sanction and enforcement and provide a more effective analysis that reflects real-world conditions.

Finally, challenging the research framework with new data would be a value addition. As not a lot of cases are explained by this combination of conditions, the study can be taken further by introducing other theoretically relevant variables such as private sector investment, public perception, the role of media, etc. QCA, having been established as a potential technique in explaining the transition to EVs, would yield interesting results when extended to other contexts. This study on India can be replicated in other economies with heterogeneous characteristics. The role of policy and regional factors in EV adoption establishes the importance of decentralization. Hence, even extending this study to the city level would produce more detailed results.

5.3. Policy Implications

For policymakers, the research outcomes highlight the major role of leveraging local assets to formulate tailored policy strategies to promote EV adoption. As described above, the research has identified five causal pathways for improving consumer demand, supply, and innovation. The research primarily highlights the role of an extensive charging network, an established EV industry, and investment in manufacturing and innovation for industry stakeholders.

Targeted Incentives: In this regard, the findings advocate for the implementation of policy incentives that complement the existing regional resources for a positive push towards higher EV deployment. The role of incentives, concessions, and interventions by the government are crucial for both consumers and producers to transition from ICEVs. While financial incentives are crucial in driving EV adoption in regions with lower incomes, their role is marginal in wealthier states. Moreover, policy incentives in driving EV supply are more efficient in regions with an established EV and automotive industry. Therefore, an assessment of the local economic landscape and industry readiness ensures that the resources are directed in regions that would have a significant impact.

Prioritising Infrastructure: While populations with higher per capita income do not rely on government incentives to shift to EVs, the policies need to focus on creating a network of public charging stations, sufficient to cater to the increasing EV use. In terms of infrastructure, mandating all government and commercial buildings, and upcoming residential buildings to install charging and swapping stations, through regulations or amending building bye-laws, reduces range anxiety in consumers, a major barrier in EV adoption. Integrating renewable energy generation into EV infrastructure planning is a viable option and encourages cross-sectoral collaboration.

Decentralization: With proximity to the local conditions, the city governments are equipped to handle the unique needs of the local population. Therefore, decentralizing to the city level is important, especially in increasing demand. This is done through collaboration with universities, public awareness to help increase consumer demand, and capacity-building initiatives for professionals, spearheading the workforce shift to the electric mobility ecosystem.

Long-term financial sustainability: As seen in the case of Goa where the financial incentives phased out over the policy period while maintaining infrastructural and innovation support even in a mature market, the EV strategies must ensure fiscal sustainability in the long run. The policy planning must ensure a gradual reduction in direct subsidies and concessions while maintaining the market viability. This balances short-term financial planning and long-term market stability, ensuring the sustainability of EV policies.

In this regard, the guiding parameter in EV adoption should be *not just more* policies, but more *contextual and targeted* policies.

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Appendix 2: Raw Data – Demand Side Conditions

Financial Incentives (in Rs.)

State	Vehicles												
	Purchase incentive				Early Bird incentive					Scrapping Incentive			
	2 wheelers	3 wheelers	4 wheelers	Bus	2 wheelers	3 wheelers	4 wheelers	Bus	Battery	2 wheelers	3 wheelers	4 wheelers	Bus
Andaman & Nicobar Island	20000	30000	100000	800000	24000	40000	120000	1000000	120000	5000	10000	25000	50000
Andhra Pradesh													
Arunachal pradesh	30000	50000	200000										
Assam	20000	50000	150000										
Bihar	10000		150000										
Chandigarh	30000	30000	150000							5000		7000	
Chhattisgarh	150000	150000	150000										
Delhi	30000	30000	150000							5000	7500		
Goa	30000	60000	300000							5000	10000	10000	
Gujarat	150000	500000	1500000										
Haryana		25000	100000										
Himachal Pradesh	0	0	0	0									
Jharkhand	10000	30000	150000	2000000									
Karnataka													
Kerala	0	30000	0	0									
Madhya Pradesh	0	0	0	0									
Maharashtra	10000	30000	150000	2000000						7000	15000	25000	
Manipur	0	0	0	0									
Meghalaya	150000	500000	1500000	20000000									
Odisha	5000	12000	100000	2000000									
Punjab	10000	30000	0	0									
Rajasthan	10000	20000	50000	500000									
Tamil Nadu	30000	40000	150000	1000000									
Uttar Pradesh	5000	12000	100000	2000000									
Uttarakhand	7500	0	50000	0									
West Bengal	10000	30000	150000	1000000	50000	50000	50000						

Raw Data

State	EV Penetration (%)	FI (in Rs.)	NFI	PCS (per 1000 sq. km)	Per Capita Income (in Rs.)
Andaman & Nicobar Island	0.34	2444000	0	0.36	229080
Andhra Pradesh	4.01	1000000	1	2.01	219518
Arunachal Pradesh	0.08	280000	0	0.11	205645
Assam	9.89	220000	1	1.10	118504
Bihar	7.24	160000	1	1.32	54111
Chandigarh	12.40	222000	1	105.26	333932
Chhattisgarh	7.70	450000	1	1.10	133898
Delhi	11.55	222500	1	1271.75	444768
Goa	12.04	415000	1	30.52	472070
Gujarat	5.37	2150000	0	2.43	241930
Haryana	4.12	125000	1	8.53	296685
Himachal Pradesh	0.97	0	1	0.79	222227
Jharkhand	4.10	2190000	1	1.69	91874
Karnataka	9.55	0	0	26.75	301673
Kerala	10.43	30000	1	24.66	233855
Madhya Pradesh	5.08	0	1	1.11	140583
Maharashtra	8.29	2237000	1	10.02	215233
Manipur	1.57	0	0	0.76	91560
Meghalaya	0.31	22150000	0	0.94	112737
Odisha	6.51	2117000	1	1.27	149902
Punjab	4.35	40000	1	3.14	181716
Rajasthan	7.16	580000	1	1.46	156149
Tamil Nadu	5.26	1220000	0	4.94	275583
Uttar Pradesh	8.69	2117000	1	2.42	83565
Uttarakhand	6.86	57500	1	1.42	233565
West Bengal	2.23	1340000	0	3.58	141373

Appendix 3: Raw Data – Supply Side Conditions

Financial Incentives (in Rs.)

Charging Infrastructure			R&D			Manufacturing							
- Capital subsidy	- Incentive for setting up	- Reduction in Electricity/ energy charges	- Incentives for setting up	- Stipend for training/ Training reimbursement	- Research grant	Capital Subsidy	Clean production measures	Sustainable green measures	Auto cluster and automotive suppliers manufacturing centres (ASMC)	Marketing	Water Supply	Others
	510000											
	1000000			10000	5000000000	76375000	3500000	500000000	200000000	500000	20000000	
						29125000						
1000000						10000000						
	1000000											
	6000	500000	500000									
1000000						62100000						
	6000											
		800000		10000		52000000						
1000000												
				500000		10000000						
700000												
	5000000			10000		3500000						12500000
1000000						2500000						
1000000												
1000000												
	5000					11250000						
10000												
500000												
	1000000					16000000						48000
1000000				5000								6000000
				5000								600000

Raw Data

State	EV Adoption	FI (in Rs.)	NFI	Industry	Per Capita GDP (in Rs.)
Andaman & Nicobar Island	278	5,10,000	0	0	163,138,000
Andhra Pradesh	74,238	5,801,385,000	0	1	123,526,000
Arunachal Pradesh	33	29,125,000	0	0	111,776,000
Assam	227,248	11,000,000	1	0	69,826,000
Bihar	205,048	1,000,000	0	0	3,128,000
Chandigarh	10,871	1,006,000	1	0	219,778,000
Chhattisgarh	70,122	63,100,000	1	0	83,511,000
Delhi	261,091	6000	1	0	271,019,000
Goa	16,364	52,810,000	1	0	310,201,000
Gujarat	169,689	1,000,000	0	0	170,384,000
Haryana	81,413	10,500,000	1	0	181,961,000
Himachal Pradesh	2722	0	1	0	152,376,000
Jharkhand	46,149	700,000	0	0	56,133,000
Karnataka	300,811	21,010,000	0	1	176,383,000
Kerala	125,356	3,500,000	0	0	14,881,000
Madhya Pradesh	126,351	1,000,000	0	0	65,023,000
Maharashtra	382,290	1,000,000	1	0	13,849,000
Manipur	1254	0	1	0	49,602,000
Meghalaya	177	0	1	0	65,114,000
Odisha	82,194	11,255,000	1	0	87,361,000
Punjab	63,077	10,000	0	0	123,614,000
Rajasthan	220,972	500,000	1	1	86,134,000
Tamil Nadu	196,428	17,048,000	0	1	166,727,000
Uttar Pradesh	704,044	7,005,000	0	0	47,066,000
Uttarakhand	56,369	605,000	0	0	158,245,000
West Bengal	75,193	0	1	0	75,561,000

Appendix 4: Demand Side – Necessary Conditions and Solutions

Necessary Disjunctions:

	inclN	**RoN**	**covN**
~Demand_FI + Demand_NFI	0.970	0.384	0.595
Demand_FI + Demand_NFI	0.925	0.194	0.507
Demand_NFI + ~PCS	0.916	0.220	0.511
Demand_NFI + PCS	1.000	0.366	0.602
Demand_NFI + Per_Capita_Income	1.000	0.274	0.570
~PCS + Per_Capita_Income	0.925	0.265	0.530
PCS + ~Per_Capita_Income	0.953	0.341	0.571

Although the disjunctions have high consistency scores depicting the degree to which the combination of conditions is a superset of the outcomes, the very low relevance of necessity scores shows the trivialness of these conditions.

Conservative Solutions:

	inclS	***PRI***	***covS***	***covU***	***Cases***
*FI*NFI*PCS*	0.895	0.868	0.289	0.289	*Goa, Maharashtra, Uttar Pradesh*
~FI~NFI*PCS*Per_Capita_Income*	0.943	0.931	0.090	0.090	*Karnataka*
M1	0.906	0.883	0.379		

Parsimonious Solutions:

M1: FI*NFI*PCS + (~FI*~NFI*PCS) → EV_Penetration

M2: FI*NFI*PCS + (~FI*~NFI*Per_Capita_Income) → EV_Penetration

	inclS	***PRI***	***covS***	***covU***	***Cases***
*FI*NFI*PCS*	0.895	0.868	0.289	0.289	*Goa, Maharashtra, Uttar Pradesh*
~FI~NFI*PCS*	0.891	0.872	0.090	0.00	*Karnataka*
~FI~NFI*Per_Capita_Income*	0.680	0.638	0.090	0.00	*Karnataka*
M1	0.894	0.869	0.379		
M2	0.833	0.796	0.379		

Appendix 5: Supply Side - Necessary Conditions and Solutions

Necessary Disjunctions:

In cases of complex phenomena like EV, often multiple conditions either in conjunction or disjunction becomes necessary. Therefore, the conditions were tested for necessary conjunctions or disjunctions that yielded the following results:

	inclN	**RoN**	**covN**
GDP + ~EV_Industry	0.944	0.082	0.507
~Supply_FI + ~Supply_NFI + ~GDP	0.959	0.229	0.558
Supply_FI + ~Supply_NFI + ~GDP	0.909	0.215	0.528
Supply_FI + Supply_NFI + ~GDP	0.955	0.241	0.560
Supply_FI + Supply_NFI + GDP	0.929	0.205	0.535
~Supply_FI + ~Supply_NFI + ~EV_Industry	0.999	0.004	0.515
Supply_FI + Supply_NFI + ~EV_Industry	1.000	0.001	0.515
~Supply_FI + ~GDP + EV_Industry	0.930	0.319	0.574
Supply_FI + ~GDP + ~EV_Industry	0.984	0.019	0.511
~Supply_NFI + ~GDP + ~EV_Industry	0.984	0.019	0.511
Supply_NFI + ~GDP + EV_Industry	0.919	0.312	0.566
Supply_FI + ~Supply_NFI + GDP + EV_Industry	0.934	0.263	0.557

Conservative Solutions:

M1: FI*~NFI*EV_Industry*GDP + FI*~NFI*~EV_Industry*~GDP +
~FI*NFI*EV_Industry*~GDP → EV_Adoption

	inclS	***PRI***	***covS***	***covU***	***Cases***
FI~NFI*EV_Industry*GDP*	0.887	0.860	0.176	0.176	*Andhra Pradesh, Karnataka, Tamil Nadu*
FI~NFI*~EV_Industry*~GDP*	0.874	0.831	0.207	0.207	*Kerala, Uttar Pradesh*
*~FI*NFI*EV_Industry*~GDP*	1.000	1.000	0.057	0.057	*Rajasthan*
M1	0.894	0.866	0.440		

Parsimonious Solutions:

M1: EV_Industry + FI*~NFI*~GDP → EV_Adoption

	inclS	*PRI*	*covS*	*covU*	*Cases*
EV_Industry	0.838	0.812	0.250	0.225	*Andhra Pradesh, Karnataka, Rajasthan, Tamil Nadu*
FI~NFI*~GDP*	0.886	0.832	0.232	0.207	*Kerala, Uttar Pradesh*
M1	0.854	0.819	0.457		

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