

Barriers or Boosters? Understanding (De)Motivating Factors in the Adoption of Home-Based Solar EV Charging Solutions

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Abstract

The integration of home solar photovoltaic (PV) systems with electric vehicle (EV) charging infrastructure has gained more popularity with the advancement towards low-carbon electric vehicles and localized solar energy systems. Although the use of electric vehicles and solar PV systems has been widely researched, the integration of these two has not been studied much, particularly in the context of emerging economies' densely populated urban centers. Using the mixed-method, user-centric approach, the study has initiated the analysis with the use of focus groups with important stakeholders to identify the key factors for the integration of solar PV systems with electric vehicle charging infrastructure. Causal interdependencies are then formulated, and these factors are prioritized under uncertainty with the use of the multi-criteria decision-making framework, namely, Grey DEMATEL. The results indicate the key driving factors such as improved customer comfort, advancements in the use of renewable energy, and the availability of government incentives. Conversely, the barriers to the integration of solar PV systems with electric vehicle charging infrastructure are found to be the limited energy storage capacity, the lack of home charging infrastructure, and the lack of solar energy availability during off-peak hours. This study has highlighted the policy interventions to improve the solar PV charging barriers with the use of streamlined subsidies, effective public education, and advancements in technology, which could be useful for the wider acceptance of solar-powered electric vehicle charging infrastructure, thereby achieving the sustainability objectives.

Keywords- Solar charging, Electric vehicle, Policymaking, User perception, MCDM.

1. Introduction

To reach the goals of the Paris Agreement and the UN's Sustainable Development Goals (SDGs), which put a high priority on clean, affordable energy (SDG 7), sustainable cities (SDG 11), and taking action on climate change right away (SDG 13), it is now thought that it is important to decarbonize both the transportation sector and the electrical grid (UN Department of Economic and Social Affairs, 2022; Electric Vehicles Initiative, 2023). The decarbonization of the transport activities favour a wider adoption of electric vehicles (EV), yet widespread availability of EV charging points poses significant challenges for adoption. The integration of charging infrastructure with residential areas with rooftop solar photovoltaics (PV) which enables drivers to replenish their vehicles directly from on-site clean energy, reducing carbon emissions, mitigating peak-demand charging stresses, and shielding consumers from time-of-use price fluctuations (Franke and Krems, 2013; Machura and Li, 2019; Morrissey et al., 2016). The global transition toward sustainable mobility and energy systems has brought EVs and residential renewable energy technologies to the forefront of urban decarbonization strategies. Home-based solar-powered EV charging systems are increasingly recognized for their ability to cut household carbon emissions, boost energy self-sufficiency, and gradually reduce urban transportation expenses (Noel et al., 2019; Rezvani et al., 2015).

When implemented at the household level, home-based solar-powered EV charging systems can simultaneously reduce emissions from both electricity generation and transportation, while also delivering multiple additional benefits such as lower overall lifetime costs, improved energy self-sufficiency, strengthened grid stability, and expanded opportunities for demand-side energy management (Wang et al., 2021; Wolbertus and Van den Hoed, 2019). Although extensive research has examined the adoption of EVs and solar PV systems individually, relatively little attention has been given to understanding the distinctive decision-making processes associated with adopting both technologies together at the residential level (Huang et al., 2021; Kester et al., 2018). To address these dynamics, it is crucial to understand the environmental and economic benefits of these EV based technologies. The household adoption of solar roof top is linked with the combination of various factors such as psychological, financial, social, and infrastructural influences of users (Kester et al., 2018; Rezvani et al., 2015; Sovacool et al., 2018). These factors are required further consideration of the address to improve the adoption of solar charging system. The solar based charging system is influenced by high initial capital costs for PV systems, limitation of battery storage, and cost of charging equipment in emerging economies (Morrissey et al., 2016). Other challenges are related to technical interoperability such as smooth integration of solar PV systems into home battery storage. The above integration of solar PV charging system with EVs also impact system reliability, ongoing equipment maintenance, and the quality support (Rezvani et al., 2015; Wolbertus and Van den Hoed, 2019). The Solar PV charging system also having a huge impact of behavioural and contextual factors along with financial and economic challenges. Apart from this, densely populated urban areas having limited rooftop availability and design of building which also restrict the installation of residential solar systems (Berkeley et al., 2018). In context of Indian EV ecosystem various central and state government mission supporting the wider adoption of solar PV based charging system to improve the grid load and urban sustainability. Indian national programs such as FAME-II offer various incentives mechanism for individuals to use EV based mobility. But lack of coordination among the EV stakeholders limits wider adoption of solar PV system (Sharma et al., 2024). Additionally, there is a lack of research employing mixed-method or systems-based approaches, particularly those designed to uncover the causal relationships between motivating and inhibiting factors in the adoption of PV systems for EV charging adoption in emerging economies (Machura and Li, 2019; Will and Schuller, 2016). The above research and practice gap are addressed with a multi-criteria decision-making method to examine the adoption dynamics among the EV users. The research study design with the detailed brainstorming session with the EV stakeholders and followed by the identification of motivating and de-motivating factors. The following key questions framed after the detailed discussion with the EV stakeholders.

- What are the key criteria for EV users to adopt solar EV charging system?
- How do users and EV stakeholders prioritise key motivating and demotivating factors?

The above RQs are addressed with the development of study specific objectives such as:

- To identify and measure their inter-influence of motivating and demotivating factor on adoption of home-based solar EV charging system.
- To apply a multi-criteria decision-making method to evaluate and prioritize the relative importance of these factors.

To map and analyze the interdependencies among these factors, the Decision-Making Trial and Evaluation Laboratory (DEMATEL) method is employed. DEMATEL, an established multi-criteria decision-making (MCDM) tool, is especially well-suited for visualizing causal relationships in complex sociotechnical systems and for distinguishing “cause” factors—like clarity of financial incentives and reliability of turnkey installation from “effect” outcomes such as user satisfaction or market scalability (Gabus and Fontela, 1972; Kumar and Anbanandam, 2020).

Reminder of the article is arranged in following order. Section 2 presents the literature review and (de) motivating factors. Section 3 presents the computational steps of grey-DEMATEL methods, followed by the study case analysis in Section 4. The result discussion and implications are given in Section 5. Section 6 conclude the study along with future extension of presented study.

2. Literature Review

The convergence of EV and solar PV technologies offers a sustainable, decentralized, and economically attractive pathway for personal mobility and residential energy consumption. Home-based solar-powered EV charging systems exemplify this convergence by enabling consumers to harness clean energy for transportation while potentially reducing costs and dependency on the conventional power grid. However, despite growing policy support and technological readiness, the adoption rate of such systems remains far below potential (Franke and Krems, 2013; Machura and Li, 2019). The low running cost of plug-in electric vehicles (PEVs) including battery electric vehicles (BEVs) and plug-in hybrid electric vehicles (PHEVs) is a major motivator for adoption (Adnan et al., 2018). Liang et al. (2022) explored consumers EV charging behavior after installation of solar PV with a data of Arizona state. The findings suggests that adoption of solar PVs adoption reduces peak hour load on grid. Chakraborty et al. (2023) explored adoption of rooftop solar co-adoption decision among residents of California and concluded that incentive mechanism for improving adoption. Authors also discussed about various economic advantages. Irfan et al. (2021) explored solar PV among Indian households through a probit model for entrepreneurial characteristics. These economic advantages stem primarily from reduced fuel costs and maintenance compared to internal combustion engine (ICE) vehicles. For home-based solar EV users, charging from a self-owned PV system could further reduce costs, particularly in regions with high grid electricity tariffs. The use of solar-generated electricity for EV charging will also reduce the cost of per unit electricity consumption which help to design a low-cost fuelling. However, public charging infrastructure have limited access to the solar PV based charging options along with free charging option at workplace has incentivized PEV purchases (Hardman et al., 2017), which may lead to congestion and other negative externalities at charging points (Hardman, 2019). Hence, it required to have balanced economic incentives that prevent the misuse of infrastructure.

Government also offers many incentives such as tax credits, charging cost rebates, and subsidies have been traditionally instrumental in increasing the adoption of EVs and home solar PV installations. Hardman et al. (2017) study highlights that investments for developing EV charging infrastructure only worthwhile if they are supported by targeted policies such as minimising upfront cost of PEV acquisition. Innovation in transportation technology, particularly in smart grids, provides an added incentive. V2G and V2H enable bidirectional energy flow such that EVs can serve as rolling storage devices (Machura and Li, 2019; Teoh et al., 2018). Dependence on EVs serving home energy demand may lower their utility availability serving transportation needs during peak demand hours. Hence, although integration of batteries provides operational advantages, cost factor and lifestyle implications set back widescale adoption. Charging patterns feature prominently in the adoption and feasibility of home-based solar EVs (Yang et al., 2023). Hence, although technological solutions are available, perceived affordability and reliability of these transport means still influence adoption choices. Perhaps the single most important factor influencing adoption of EVs remains access to easily accessible charging facilities. Surveys have uniformly revealed home charging to be the single most important location factor influencing purchase behavior, both convenience and usage profile (Hardman, 2019). Its second-most important rival was workplace charging, and although lesser used, even public charging remains an important shaping factor of consumer perception (Morrissey et al., 2016).

The preference for home charging aligns well with the solar adoption model, as residential PV systems can support routine charging needs. Thus, consumers with access to private parking and suitable rooftops are more likely to find the home-based solar EV system appealing. However, those living in apartments or shared housing often lack such access, significantly limiting their ability to adopt these systems. The adoption of home-based solar electric vehicle (EV) charging systems is influenced by several motivating and demotivating factors. Economically, users are attracted by the lower running costs of plug-in electric vehicles (PEVs), especially when powered by self-generated solar energy (Rezvani et al., 2015). Government incentives, including tax credits and rebates, further support adoption (Hardman et al., 2018). Technological innovations like smart grids and bidirectional power flows (V2G/V2H) offer users energy independence and income opportunities while enhancing grid resilience (Barman et al., 2023; Will and Schuller, 2016; Yi et al., 2018). Convenience, especially the ability to charge at home, is also a key motivator (Hardman et al., 2018). Zhang et al. (2026) developed a regression based model with five identified gaps on 37 international V2G user survey and concluded that complexity of economic compensation on users' willingness to participate in V2G.

One of the major drivers of PEV adoption is the low operating costs of plug-in electric vehicles (PEVs), which include battery electric vehicles (BEVs) and plug-in hybrid electric vehicles (PHEVs) (She et al., 2017). The cost benefits of PEVs are mostly linked to fuel and operating costs compared to those of internal combustion engine vehicles. For home-based solar-powered EV users, there is an opportunity to save on fuel costs, especially when they are in areas with high electricity tariffs. With electricity generated from their own PV systems to power EVs, there is a possibility of avoiding uncertainty in electricity rates.

Table 1. Motivating factors for adopting a solar power-based charging system.

Motivating factor (code)	Key references
Low running costs of PV based charging (M1)	Hawkins et al. (2012), Quak et al. (2016)
Adequate Government incentives for adopting PV charging system (M2)	Machura and Li (2019), Morrissey et al. (2016)
Provide a bidirectional power flow (M3)	Franke and Krems (2013)
Help to improve smart grid integration (M4)	Will and Schuller (2016)
Enhanced User Convenience and Adoption Confidence (M5)	Machura and Li (2019), Morrissey et al. (2016)
Provide consumers with dynamic uses traffic (M6)	Franke and Krems (2013)
Solar based charging provides environmental Benefits and emission reductions (M7)	Kampker et al. (2020), Quak et al. (2016)
Improve energy autonomy and rural access (M8)	Yap et al. (2022)
Advancing renewable energy deployment for EV industry (M9)	Gonzalez-Salazar et al. (2023)

Table 2. De-motivating factor for solar charging adoption.

Demotivating factor (code)	Key references
High upfront cost of PV panel installation (D1)	Morrissey et al. (2016)
High cost of PV battery maintenance (D2)	Franke and Krems (2013), Will and Schuller (2016)
Intermittency of Solar Energy Generation (D3)	Will and Schuller (2016)
Lack of knowledge and awareness about PV based charging system (D4)	Morrissey et al. (2016), Wang et al. (2021)
Non-availability of solar energy in off-day hours ((D5)	Teoh (2021), Teoh et al. (2018)
Lack of access to home charging infrastructure (D6)	Kumar et al. (2021), Xu et al. (2020)
Limited space in urban or shared housing layout (D7)	Dorcec et al. (2019)
Complexity of PV technology integration with EV (D8)	Karmaker et al. (2018), Xu et al. (2020)
Limited capacity without energy storage (D9)	Experts input

Government incentives such as tax credits, rebates, and subsidies have been effective in promoting the adoption of EVs and residential solar PV panels in the past. The analysis done by Hardman et al. (2017) on the development of infrastructure, which on its own is considered to be a poorly targeted policy, and the cost of the purchase of PEV being equally important, has been highlighted. However, the rate of adoption

of these vehicles and solar PV panels, despite the incentives, has been slow compared to what the government had envisaged, and therefore the need to adopt integrated policies, which offer incentives for the adoption of EVs and solar PV simultaneously, has been highlighted. Motivating and demotivating factors are highlighted in **Tables 1** and **2**.

2.1 Research Gap and Novelty

While electric vehicles (EVs) and solar photovoltaic (PV) technology have been studied assiduously in academia and policymaking in their own respects, research examining their cumulative adoption, namely home-based solar-powered EV charging system are virtually underdeveloped (Global EV Outlook, 2024). Most are focused on either EV or solar energy adoption in single settings and thus overlook the complex and unique interplay of motivators and inhibitions faced by consumers considering these two technologies together (Axsen et al., 2013). This fragmentation offers a primary gap in knowledge in the evaluation of bundle technologies, with the adoption process entailing greater financial investment, functional integration, and lifestyle adjustments than its single-technology counterparts (Noel et al., 2019). Additionally, while cost savings and subsidy effects have been studied extensively in their persuasiveness of adoption of EV or PV technology, accounting for these benefits is utilized and weighted differently when technology combinations are co-adopted offers even fewer informed analyses (Hardman et al., 2017; Rezvani et al., 2015). In addition, past studies overlook critical contextual challenges such as home ownership, limited roof access, or sunlight availability which are largely in a position to constrain install feasibility of home-based solar-powered EV charging system significantly (Sovacool et al., 2018). Another gap in literature evident extends to the information and behavior components. Many prospective adopters are discouraged not by cost only, but by unfamiliarity with system advantages, integration difficulties, or future reliability (Will and Schuller, 2016). The propensity to perceive consumers as rational economic agents cannot capture the subtle, and sometimes cautious, decision-making processes moderated by trust, awareness, and perceived dangers (Goel et al., 2023). Third, although some studies document the contributions of workplace charging and public facilities to facilitating EV adoption, very few have explored intersections of access to or inability to access private home charging facilities and solar adoption choices. This is true more often for urban residents or renters, who are frequently left behind such shifts even though they have environmental interest.

3. Research Methods

In the rapidly evolving domain of solar-based EV charging systems, decision makers face intertwined technical, economic, and environmental criteria under uncertainty. The Grey Decision-Making Trial and Evaluation Laboratory (Grey DEMATEL) method based on Grey System Theory (Deng, 1989) to elucidate causal relationships among factors with imprecise expert judgments. This hybrid approach enhances interpretability and prioritization in the evaluation of solar EV charging infrastructures, supporting stakeholders in identifying critical drivers and formulating resilient deployment strategies. The following steps are required for proposed method.

Step 1: *Initial direct relation matrices from experts*

Table 3. Grey linguistic scale.

Linguistic opinion	Range of grey sets	Crisp value
No influence (N)	[0,0]	0
Low influence (L)	[0, 0.25]	1
Medium influence (M)	[0.25, 0.5]	2
High influence (H)	[0.5,0.75]	3
Very high influence (VH)	[0.75,1]	4

In a decision-making process, ‘ p ’ number of experts, taking the influence rating from criteria ‘ i ’ on criteria ‘ j ’ based on the linguistic opinion, is converted into a range of grey sets as shown in **Table 3**. The grey scale is referred as (0,0), (0,0.25), (0.25,0.5), (0.5,0.75), (0.75,1), and expert is represented with ‘ l ’.

Step 2: Computation of average grey relation matrix (AGRM) and normalisation

Let us take the grey number for expert ‘ l ’ as representing the influence information of criteria ‘ i ’ and criteria ‘ j ’ by expert ‘ l ’ in the direct relation matrix and lower and upper values, shown in Equation (1). With ‘ p ’, grey relation matrices form the average relation matrix from all individual expert opinions, which is given in **Table 4**, and the normalisation process from Equations (3)-(6), based on the method presented by (Opricovic and Tzeng, 2003).

$$\otimes G_{ij}^l = [\underline{\otimes} G_{ij}^l, \bar{\otimes} G_{ij}^l] \tag{1}$$

$$\otimes \tilde{G} = \left[\frac{\sum_{l=1}^p \underline{\otimes} G_{ij}^l}{p}, \frac{\sum_{l=1}^p \bar{\otimes} G_{ij}^l}{p} \right] \tag{2}$$

$$\Delta_{\min}^{\max} = \max_j \bar{\otimes} \tilde{G}_{ij} - \min_j \underline{\otimes} \tilde{G}_{ij} \tag{3}$$

$$\underline{\otimes} G = \frac{(\underline{\otimes} \tilde{G}_{ij} - \min_j \underline{\otimes} \tilde{G}_{ij})}{\Delta_{\min}^{\max}} \tag{4}$$

$$\bar{\otimes} G_{ij} = \frac{(\bar{\otimes} \tilde{G}_{ij} - \min_j \bar{\otimes} \tilde{G}_{ij})}{\Delta_{\min}^{\max}} \tag{5}$$

$$C_{ij} = \left[\frac{\underline{\otimes} G_{ij} (1 - \underline{\otimes} G_{ij}) + (\bar{\otimes} G_{ij} \times \bar{\otimes} G_{ij})}{(1 - \underline{\otimes} G_{ij} + \bar{\otimes} G_{ij})} \right] \tag{6}$$

From (Kumar and Anbanandam, 2020), Equations (7) to (12a) are considered. The conversation for grey numbers into crisp numbers is given in Equation (7), B is the crisp relation matrix and X denotes normalisation factor.

$$C_{ij}^* = \left[\min \underline{\otimes} \tilde{G}_{ij} + (C_{ij} \times \Delta_{\min}^{\max}) \right] \tag{7}$$

$$C = [C_{ij}^*] \tag{8}$$

$$B = C * X \tag{9}$$

$$X = \frac{1}{\max_{1 \leq i \leq n} \sum_{j=1}^n C_{ij}^*} \tag{10}$$

Step 3: Generating total relation matrix (TRM)

The total relation matrix ‘ T ’ is calculated using normalised crisp direct relation matrix ‘ B ’, ‘ T ’ is calculated by Equation (11),

$$T = B \times (I - B)^{-1} \tag{11}$$

where, I , is the identity matrix.

Step 4: Calculation of cause-and-effect values

Let's, consider the sum of both direct and indirect effects of criteria 'i' on all its alternatives (j) as R_i . The sum of direct and indirect effects received by each criterion (i) to the alternative 'j' as D_j , the calculations for R_i , D_j are given in Equation (12).

$$R_i = \sum_{j=1}^n t_{ij} \forall i, \text{ and} \quad (12)$$

$$D_j = \sum_{i=1}^n t_{ij} \forall j$$

where, t_{ij} = elements of the matrix TRM.

When $i = j$, ' $R_i + D_j$ ' is called '*prominence*', which specifies the total effect given and received by the criteria 'i' on the remaining criterion presented in the system, which means it shows the importance degree of criteria 'i' in the system.

When $i = j$, ' $R_i - D_j$ ' is called '*relation*'. The total prominence (P_i) of an inhibitor 'i' and the total effect (E_i) of an inhibitor 'i' can be calculated with the following expression.

$$P_i = \{R_i + D_j \mid i = j\} \quad (13)$$

$$E_i = \{R_i - D_j \mid i = j\}$$

where, i, j range from 1, 2, ..., n.

The highest value of P_i among the criterion shows the greater importance. And if $E_i > 0$, it is a net cause to the system; if $E_i < 0$, then it depends on the other criterion present in the system.

4. Case Study and Analysis**4.1 Study Background**

Delhi's air quality remains critically poor, with particulate-matter concentrations far exceeding safe limits and transport emissions accounting for most of the urban pollution. To tackle this, the Delhi Electric Vehicle Policy 2020 has set an ambitious target of making one quarter of all new vehicle registrations battery-electric by 2024¹. Yet the transition is hampered by a shortage of accessible, reliable charging infrastructure and by the fact that most grid electricity still comes from fossil-fired power plants. At the same time, both central and state governments have rolled out generous rooftop-solar subsidies under the PM Surya Ghar Muft Bijli Yojana and Delhi's additional incentives to encourage households to install photovoltaic systems². Nevertheless, the uptake of residential systems has been hampered by complex permitting and approvals procedures, as well as unclear payback periods. There is an opportunity to fill the gaps through direct integration of home-based solar PV systems with dedicated EV charging systems. Such systems would be able to provide electricity bill savings to consumers through the use of midday sun to support evening charging demand. Furthermore, such systems would be able to provide peak demand reduction to the grid, thereby reducing lifecycle greenhouse gas emissions (World energy outlook, 2024). This research aims to identify and prioritize the critical criteria that influence or restrict the uptake of residential solar-based EV charging systems in Delhi. For this purpose, a Grey DEMATEL method would be employed to determine critical criteria such as subsidy policies, system integration periods, standardization of equipment, and grid interaction policies.

¹ <https://beeindia.gov.in/sites/default/files/Delhi.pdf>

² <https://pmsuryaghar.gov.in/#/>

4.2 Data Analysis

For the analysis of data regarding motivating and demotivating factors related to home-based solar EV charging solutions, the Grey Decision-Making Trial and Evaluation Laboratory (Grey-DEMATEL) approach has been applied. This approach is based on combining Grey System Theory and DEMATEL and is effective in demonstrating interdependencies between multiple criteria of decision-making with inherent uncertainties and imprecisions. The first step in this regard is related to developing initial matrices of direct relations based on expert opinions. For this purpose, multiple experts are involved in evaluating the influence of one criterion over another using a linguistic scale ranging from "no influence" to "very high influence." These linguistic opinions are converted into corresponding grey numerical values as per the suggested approach in the methodological framework. The next step is related to calculating the Average Grey Relation Matrix (AGRM), which is derived based on aggregating individual expert matrices. The resulting matrix is composed of grey numbers, each representing average opinions of multiple experts. The next step is related to normalizing this matrix using Equations (1)-(6), which standardize varying opinions of experts. The next step in this regard is related to converting normalized grey numbers into crisp numbers to facilitate better interpretation, as suggested in Equation (7). This process was vital in order to attain clear and distinct insights from the fuzzy expert evaluations. The crisp relation matrix (*B*) provided clear and quantified measures of direct influences between factors. This process involved using the normalized crisp direct relation matrix and combining direct and indirect relations between factors. **Table 4** presents a sample of expert responses using the grey DEMATEL method computation of aggregate grey relationship matrix and normalised decision matrix as provided in **Tables A1** and **A2**, respectively. Once normalised relationships are computed, Total Relation Matrix (TRM) is computed using Equation (11) and is provided in **Table 5**. Further calculations using Equations (12) are done to determine prominence and relation values of each criterion as provided in **Table 6**. In this case, prominence is a value that measures the total degree to which a particular criterion is influenced or influences all other criteria, thus highlighting its importance in the system. Relation values differentiate criteria as causes or effects, thus being vital in determining the direction of influence in the adoption dynamics. The same process is followed to determine demotivating factor importance and prominence, and a sample of expert responses is provided in **Table 7**.

Table 4. Impact relation assessment response- Expert 1.

Comparison matrix	M1		M2		M3		M4		M5		M6		M7		M8		M9	
	L	U	L	U	L	U	L	U	L	U	L	U	L	U	L	U	L	U
Low running costs of PV based charging (M1)	0	0	0.5	0.75	0	0.25	0.5	0.75	0.75	1	0.75	1	0.25	0.5	0.25	0.5	0.75	1
Adequate Government incentives for adopting PV charging system (M2)	0.75	1	0	0	0	0.25	0.25	0.5	0	0	0.5	0.75	0.75	1	0.75	1	0.75	1
Provide a bidirectional power flow (M3)	0.5	0.75	0.75	1	0	0	0.5	0.75	0.25	0.5	0.5	0.75	0.25	0.5	0.5	0.75	0	0.25
Help to improve smart grid integration (M4)	0.75	1	0.5	0.75	0.25	0.5	0	0	0.25	0.5	0.5	0.75	0.25	0.5	0.75	1	0.5	0.75

Table 4 continued...

Enhanced User Convenience and Adoption Confidence (M5)	0	0	0.25	0.5	0	0.25	0	0	0	0	0.75	1	0.5	0.75	0.5	0.75	0.25	0.5
Provide consumers with dynamic uses traffic (M6)	0.75	1	0.75	1	0	0	0.5	0.75	0.75	1	0	0	0.25	0.5	0	0	0.5	0.75
Solar based charging provides environmental Benefits and emission reductions (M7)	0	0.25	0.25	0.5	0.75	1	0	0	0.5	0.75	0	0.25	0	0	0.5	0.75	0.25	0.5
Improve energy autonomy and rural access (M8)	0.5	0.75	0.25	0.5	0.5	0.75	0.5	0.75	0.5	0.75	0.5	0.75	0.25	0.5	0	0	0.5	0.75
Advancing renewable energy deployment for EV industry (M9)	0.75	1	0.25	0.5	0.25	0.5	0.75	1	0.5	0.75	0.5	0.75	0.25	0.5	0.75	1	0	0

Note: L: Lower bound value of grey number; U: Upper bound value of grey number.

Table 5. Total relationship matrix.

Comparison matrix	M1	M2	M3	M4	M5	M6	M7	M8	M9
M1	0.370	0.530	0.205	0.434	0.545	0.620	0.393	0.454	0.475
M2	0.549	0.478	0.208	0.461	0.517	0.646	0.477	0.557	0.540
M3	0.385	0.454	0.138	0.338	0.417	0.491	0.316	0.373	0.370
M4	0.535	0.556	0.267	0.355	0.508	0.612	0.392	0.515	0.490
M5	0.282	0.403	0.141	0.302	0.314	0.493	0.347	0.354	0.375
M6	0.510	0.580	0.188	0.444	0.573	0.500	0.395	0.485	0.506
M7	0.269	0.394	0.199	0.277	0.389	0.381	0.224	0.328	0.346
M8	0.502	0.581	0.251	0.443	0.554	0.649	0.384	0.408	0.539
M9	0.559	0.656	0.271	0.541	0.636	0.713	0.458	0.578	0.468

Table 6. Cause and effect analysis of motivating factor.

Motivating factors	R+C	R-C	Rank	Cause/effect
Low running costs of PV based charging (M1)	7.989	0.066	5	Cause
Adequate Government incentives for adopting PV charging system (M2)	9.064	-0.199	2	Effect
Provide a bidirectional power flow (M3)	5.152	1.413	9	Cause
Help to improve smart grid integration (M4)	7.826	0.635	6	Cause
Enhanced User Convenience and Adoption Confidence (M5)	7.462	-1.445	7	Effect
Provide consumers with dynamic uses traffic (M6)	9.287	-0.923	1	Effect
Solar based charging provides environmental Benefits and emission reductions (M7)	6.193	-0.578	8	Effect
Improve energy autonomy and rural access (M8)	8.363	0.260	4	Cause
Advancing renewable energy deployment for EV industry (M9)	8.988	0.770	3	Cause

Demotivating factors aggregate decision matrix and normalised decision matrix is given in **Tables B1** and **B2** respectively. The TRM of demotivating factors are given in **Table 8** and further categorization of cause-and-effect factors are presented in **Table 9**.

Table 7. Initial relationship matrix of demotivating factor- Expert 1.

Comparison matrix	D1		D2		D3		D4		D5		D6		D7		D8		D9	
High upfront cost of PV panel installation (D1)	0	0	0.5	0.75	0	0.25	0	0.25	0.25	0.5	0.5	0.75	0.75	1	0.5	0.75	0.25	0.5
High cost of PV battery maintenance (D2)	0.25	0.5	0	0	0.5	0.75	0.5	0.75	0.25	0.5	0.75	1	0	0.25	0.75	1	0.5	0.75
Intermittency of Solar Energy Generation (D3)	0	0.25	0	0	0	0	0.25	0.5	0.75	1	0.25	0.5	0.25	0.5	0	0.25	0.25	0.5
Lack of knowledge and awareness about PV based charging system (D4)	0.25	0.5	0	0.25	0	0.25	0	0	0.25	0.5	0.75	1	0.25	0.5	0.75	1	0.25	0.5
Non-availability of solar energy in off-day hours ((D5)	0.25	0.5	0	0.25	0.75	1	0.5	0.75	0	0	0.25	0.5	0.5	0.75	0.25	0.5	0.5	0.75
Lack of access to home charging infrastructure (D6)	0.5	0.75	0.25	0.5	0	0.25	0.5	0.75	0.25	0.5	0	0	0.5	0.75	0.5	0.75	0.5	0.75
Limited space in urban or shared housing layout (D7)	0	0.25	0	0	0	0.25	0.25	0.5	0.5	0.75	0	0.25	0	0	0.25	0.5	0.25	0.5
Complexity of PV technology integration with EV (D8)	0.25	0.5	0.25	0.5	0	0.25	0.5	0.75	0.5	0.75	0.5	0.75	0.5	0.75	0	0	0.25	0.5
Limited capacity without energy storage (D9)	0.5	0.75	0.25	0.5	0	0	0.25	0.5	0.5	0.75	0.25	0.5	0.25	0.5	0.25	0.5	0	0

Table 8. Total relationship matrix.

Comparison matrix	D1	D2	D3	D4	D5	D6	D7	D8	D9
D1	0.441	0.458	0.158	0.542	0.705	0.680	0.491	0.600	0.666
D2	0.678	0.507	0.210	0.623	0.778	0.753	0.613	0.724	0.809
D3	0.399	0.313	0.104	0.374	0.511	0.483	0.343	0.396	0.487
D4	0.604	0.487	0.254	0.456	0.651	0.692	0.482	0.634	0.641
D5	0.449	0.512	0.183	0.547	0.539	0.661	0.507	0.541	0.652
D6	0.637	0.588	0.172	0.619	0.783	0.624	0.535	0.673	0.776
D7	0.309	0.366	0.115	0.390	0.470	0.375	0.270	0.383	0.460
D8	0.585	0.571	0.170	0.556	0.726	0.707	0.514	0.529	0.738
D9	0.622	0.618	0.195	0.582	0.775	0.755	0.524	0.684	0.635

Table 9. Cause and effect analysis of motivating factor.

Demotivating factors	R+C	R-C	Rank	Cause/effect
High upfront cost of PV panel installation (D1)	9.466	0.018	7	Cause
High cost of PV battery maintenance (D2)	10.116	1.274	5	Cause
Intermittency of Solar Energy Generation (D3)	4.970	1.851	9	Cause
Lack of knowledge and awareness about PV based charging system (D4)	9.592	0.211	6	Cause
Non-availability of solar energy in off-day hours ((D5)	10.529	-1.347	3	Effect
Lack of access to home charging infrastructure (D6)	11.136	-0.324	2	Effect
Limited space in urban or shared housing layout (D7)	7.420	-1.141	8	Effect
Complexity of PV technology integration with EV (D8)	10.261	-0.069	4	Effect
Limited capacity without energy storage (D9)	11.255	-0.473	1	Effect

5. Result Discussion

The tabular analysis outlined in **Tables 6 and 9** gives a comprehensive picture of the motivating and demotivating attributes shaping consumer adoption of home-based solar-powered electric vehicle (EV) charging systems in the urban Delhi context. The findings provide important insights supporting related

literature and make related practical and theoretical contributions. As shown in **Table 6** the 'dynamic use traffic' factor (M6) was ranked highest among the influencing attributes. Moreover, 'Intermittency of solar energy generation' (D3) and 'High cost of PV battery maintenance' (D2) have also emerged as major causal deterrents based on the analysis. The above findings have directly pointed to the fact that consumer concerns regarding sustainability and reliability of current and future maintenance of solar EV charging infrastructure have profound impacts on consumer preferences. The above findings have also been validated based on literature sources, as mentioned in the works of Morrissey et al. (2016) and Will and Schuller (2016), which have mentioned these issues as major consumer deterrents.

Moreover, the significant impact of 'High upfront cost of PV panel installation' (D1) as a major causal deterrent has also emerged as a major barrier, which is still significantly influential in the context of EV charging infrastructure. The above findings have pointed to the fact that initial financial investment requirements still have major impacts as barriers. Franke and Krems (2013) and Morrissey et al. (2016), in this context, have specifically emphasized the importance of high upfront costs as being critically impactful in developing economies, where financial markets are still in their developing stages. The above findings have also emphasized the importance of financial assistance programs being specifically designed and implemented for residential consumers.

Moreover, it has also emerged based on the findings that informational barriers, as mentioned in the factor 'Lack of knowledge and awareness about PV-based charging systems' (D4), have had major impacts on consumer behavior and preferences. The above findings have specifically pointed to the fact that despite monetary and environmental benefits being available, lack of awareness and knowledge have impacted consumer willingness to adopt EV charging infrastructure at lower rates. The above findings have also been validated based on literature sources, as mentioned in the works of Rezvani et al. (2015) and Wang et al. (2021), which have emphasized the importance of consumer education and awareness in completely eliminating this barrier.

Moreover, it has also emerged based on the findings that the factor 'Limited space in urban or shared housing layout' (D7) has had major impacts as a logistical barrier. The above findings have also validated earlier findings regarding infrastructural and spatial limitations. The above findings have also been validated based on literature sources, as mentioned in the work of Dorcec et al. (2019), which has emphasized the importance of house layout in influencing consumer willingness in urban settings. Shifting attention to demotivating impacts (**Table 9**), the 'Limited capacity without energy storage' (D9) factor was revealed as one of the most significant demotivating impacts. This highlights a significant infrastructural barrier, i.e., an inability of solar EV systems to perform adequately without adequate storage arrangements. This closely resembles earlier studies by Kumar et al. (2021) and Xu et al. (2020) and, who ranked energy storage as a top-of-the-line necessity in order to ensure constant and reliable operation of domestic solar charging of EVs. Without reliable and economical storage arrangements, adoption levels are thereby seriously hampered.

Another disincentive factor recognized with highest priority was the 'lack of access to home charging infrastructure' (D6). This reveals a complete logistical and spatial barrier, which indeed inhibits consumer potential to embark upon home-centric solar EV charging applications. As particularly true of highly urbanized and populated urban locations such as Delhi, absence of private parking locations or suitable rooftops imposes great constraints. Previous research works undertaken by Kumar et al. (2021) and Xu et al. (2020) give absolute credence to these findings and reveal a dire need to combine better urban planning and infrastructural development models to support widespread take-up.

Moreover, 'Intermittency of solar energy generation' (D3) and 'High cost of PV battery maintenance' (D2) have also emerged as major causal deterrents based on the analysis. The above findings have directly pointed to the fact that consumer concerns regarding sustainability and reliability of current and future maintenance of solar EV charging infrastructure have profound impacts on consumer preferences. The above findings have also been validated based on literature sources, as mentioned in the works of Morrissey et al. (2016) and Will and Schuller (2016), which have mentioned these issues as major consumer deterrents. Moreover, the significant impact of 'High upfront cost of PV panel installation' (D1) as a major causal deterrent has also emerged as a major barrier, which is still significantly influential in the context of EV charging infrastructure. The above findings have pointed to the fact that initial financial investment requirements still have major impacts as barriers. Franke and Krems (2013) and Morrissey et al. (2016), in this context, have specifically emphasized the importance of high upfront costs as being critically impactful in developing economies, where financial markets are still in their developing stages. The above findings have also emphasized the importance of financial assistance programs being specifically designed and implemented for residential consumers. Moreover, it has also emerged based on the findings that informational barriers, as mentioned in the factor 'Lack of knowledge and awareness about PV-based charging systems' (D4), have had major impacts on consumer behavior and preferences. The above findings have specifically pointed to the fact that despite monetary and environmental benefits being available, lack of awareness and knowledge have impacted consumer willingness to adopt EV charging infrastructure at lower rates. The above findings have also been validated based on literature sources, as mentioned in the works of Rezvani et al. (2015) and Wang et al. (2021), which have emphasized the importance of consumer education and awareness in completely eliminating this barrier. Moreover, it has also emerged based on the findings that the factor 'Limited space in urban or shared housing layout' (D7) has had major impacts as a logistical barrier. The above findings have also validated earlier findings regarding infrastructural and spatial limitations. The above findings have also been validated based on literature sources, as mentioned in the work of Dorcec et al. (2019), which has emphasized the importance of house layout in influencing consumer willingness in urban settings.

6. Conclusion and Future Scope

Decarbonizing the transport and electricity sectors has emerged as a pressing concern worldwide. Global accords such as the Paris Agreement and the United Nations' Sustainable Development Goals are compelling nations to do so. One such measure is the simultaneous use of residential solar photovoltaic (PV) technology and electric vehicle (EV) charging at home. This has the potential to make our cities greener and our homes more independent. In this research, the reasons for or against the adoption of solar PV and home EV charging in urban India, specifically Delhi, are explored. Delhi is plagued by critical air and traffic problems, so there is no room for error. This research is located at the crossroads of environmental sustainability, financial benefits, and energy security. Solar EV charging at home is beneficial on several fronts: greenhouse gases are reduced, there is protection against price fluctuations, and the grid is strengthened and made more robust. Despite these advantages, the adoption is still low. The reasons for this are high costs, technology, and lack of awareness. To get to the core of the problem, both qualitative and quantitative approaches focus groups and Grey DEMATEL were employed. This combination of approaches provided the full picture of how people feel, what people know, and the array of factors influencing or driving people's decisions. DEMATEL, for instance, enabled us to better understand the factors driving or blocking people's decisions to adopt or not adopt solar panels and electric vehicle charging. What people care most about are three things: good government incentives, the advancement of renewable energy, and how user-friendly the system is. On the other hand, the major hurdles are people's lack of capacity to do so without battery storage, difficulty of access to home charging, and the fact that solar energy is not always available, especially at night or during cloudy weather. Government incentives for solar panels and electric vehicle charging must be made easier for people to access, and

bureaucracy must be reduced to the minimum. People must be made aware of the long-term benefits of solar energy integrated with electric vehicle charging systems. This can be done via campaigns to highlight the benefits of these systems. Common standards must be developed to help people adopt these systems, such as new battery storage systems and solutions. This can be done via urban planning, especially in cities like Delhi, to accommodate solar panels and electric vehicle charging systems in residential areas.

Conflicts of Interest

No potential conflict of interest reported during the study phase.

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AI Disclosure

The author(s) declare that no assistance is taken from generative AI to write this article.

Appendix-A

Table A1. Aggregate grey relationship matrix.

Comparison matrix	M1		M2		M3		M4		M5		M6		M7		M8		M9	
M1	0.000	0.000	0.458	0.708	0.125	0.375	0.458	0.708	0.625	0.875	0.708	0.958	0.333	0.583	0.333	0.583	0.417	0.667
M2	0.625	0.875	0.000	0.000	0.000	0.250	0.375	0.625	0.250	0.375	0.542	0.792	0.583	0.833	0.625	0.875	0.500	0.750
M3	0.417	0.667	0.500	0.750	0.000	0.000	0.292	0.542	0.375	0.625	0.500	0.750	0.250	0.500	0.242	0.492	0.542	0.792
M4	0.667	0.917	0.458	0.708	0.375	0.625	0.000	0.000	0.292	0.542	0.500	0.750	0.250	0.500	0.542	0.792	0.750	0.900
M5	0.000	0.000	0.333	0.583	0.000	0.250	0.250	0.500	0.000	0.000	0.667	0.917	0.500	0.750	0.242	0.492	0.542	0.792
M6	0.583	0.833	0.625	0.875	0.000	0.000	0.417	0.667	0.667	0.917	0.000	0.000	0.250	0.500	0.417	0.667	0.500	0.750
M7	0.000	0.250	0.458	0.708	0.375	0.625	0.250	0.500	0.500	0.750	0.208	0.458	0.000	0.000	0.242	0.492	0.542	0.792
M8	0.417	0.667	0.458	0.708	0.250	0.500	0.292	0.542	0.417	0.667	0.542	0.792	0.167	0.317	0.000	0.000	0.500	0.750
M9	0.417	0.667	0.500	0.750	0.242	0.492	0.542	0.792	0.500	0.750	0.500	0.750	0.250	0.500	0.458	0.708	0.000	0.000

Table A2. Normalised decision matrix.

Comparison matrix	M1	M2	M3	M4	M5	M6	M7	M8	M9
M1	0.000	0.107	0.036	0.107	0.144	0.162	0.080	0.080	0.098
M2	0.158	0.000	0.011	0.097	0.055	0.138	0.148	0.158	0.127
M3	0.089	0.113	0.000	0.068	0.086	0.113	0.059	0.068	0.059
M4	0.160	0.112	0.093	0.000	0.074	0.122	0.065	0.131	0.093
M5	0.000	0.084	0.010	0.053	0.000	0.160	0.122	0.074	0.093
M6	0.141	0.150	0.008	0.102	0.160	0.000	0.065	0.097	0.116
M7	0.011	0.104	0.086	0.046	0.113	0.051	0.000	0.068	0.086
M8	0.112	0.130	0.075	0.086	0.119	0.154	0.044	0.000	0.142
M9	0.119	0.151	0.068	0.151	0.151	0.151	0.079	0.131	0.000

Appendix- B

Table B1. Aggregate grey decision matrix.

Comparison matrix	D1		D2		D3		D4		D5		D6		D7		D8		D9	
	L	U	L	U	L	U	L	U	L	U	L	U	L	U	L	U	L	U
D1	0.000	0.000	0.083	0.333	0.000	0.250	0.417	0.667	0.667	0.917	0.625	0.875	0.375	0.625	0.500	0.750	0.500	0.750
D2	0.667	0.917	0.000	0.000	0.100	0.375	0.417	0.667	0.400	0.750	0.400	0.750	0.500	0.833	0.625	0.875	0.667	0.917
D3	0.417	0.667	0.000	0.200	0.000	0.000	0.500	0.000	0.500	0.700	0.400	0.700	0.200	0.500	0.200	0.400	0.400	0.700
D4	0.500	0.833	0.200	0.400	0.400	0.600	0.000	0.000	0.200	0.500	0.500	0.700	0.200	0.500	0.500	0.700	0.200	0.500
D5	0.000	0.000	0.400	0.600	0.100	0.375	0.500	0.700	0.000	0.000	0.600	0.800	0.500	0.700	0.200	0.500	0.500	0.700
D6	0.500	0.833	0.400	0.700	0.000	0.000	0.500	0.700	0.600	0.900	0.000	0.000	0.200	0.500	0.500	0.700	0.600	0.900
D7	0.000	0.200	0.400	0.600	0.000	0.200	0.400	0.700	0.500	0.700	0.000	0.200	0.000	0.000	0.200	0.500	0.400	0.700
D8	0.400	0.667	0.400	0.700	0.000	0.200	0.200	0.500	0.500	0.700	0.500	0.700	0.200	0.500	0.000	0.000	0.500	0.833
D9	0.400	0.667	0.500	0.700	0.000	0.200	0.200	0.500	0.500	0.700	0.500	0.700	0.200	0.400	0.400	0.700	0.000	0.000

Table B2. Normalised decision matrix.

Comparison matrix	D1	D2	D3	D4	D5	D6	D7	D8	D9
D1	0.000	0.029	0.010	0.106	0.165	0.155	0.096	0.125	0.125
D2	0.165	0.000	0.038	0.100	0.115	0.115	0.145	0.155	0.165
D3	0.092	0.007	0.000	0.058	0.119	0.101	0.058	0.050	0.101
D4	0.161	0.063	0.116	0.000	0.073	0.149	0.073	0.149	0.073
D5	0.008	0.110	0.040	0.131	0.000	0.163	0.131	0.070	0.131
D6	0.145	0.115	0.000	0.125	0.165	0.000	0.077	0.125	0.165
D7	0.011	0.092	0.011	0.107	0.117	0.011	0.000	0.061	0.107
D8	0.116	0.127	0.012	0.084	0.138	0.138	0.084	0.000	0.161
D9	0.127	0.156	0.031	0.081	0.156	0.156	0.064	0.143	0.000

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