

**Filtering Factors on the Transition to Electric Vehicles Through the Perspective of
Diffusion of Innovation**

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On my honor as a University Student, I have neither given nor received unauthorized aid on this
assignment as defined by the Honor Guidelines for Thesis-Related Assignments

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Introduction

“It’s a good thing. They need to bring it to market and keep iterating and improving and make better and better electric cars, and that’s what’s going to result in humanity achieving a sustainable transport future. I wish it was growing faster than it is” says Elon Musk (Badkar, 2013). His obsession with improving the car itself may be the reason his electric vehicles (EVs) are not growing and spreading through the world faster than they are.

The need to switch to EVs seems dire and obvious with the increasing concern for climate change. Anthropogenic global warming has been established as a problem with a multitude of disastrous effects (IPCC, 2018). To limit warming to 1.5 degrees Celsius, emissions must be reduced significantly in all sectors (IPCC, 2018). The transportation sector is a major emitter; our routines of driving are responsible for a third of this country’s greenhouse gas emissions in 2019 (EPA, n.d.). Over half of US’ transportation emissions, equating to 15% of the US’ Green House Gas (GHG) emissions, came from passenger vehicles, trucks, SUVs, and minivans (EPA, n.d.). Electric vehicles must replace combustion vehicles (CVs) by 2035-2050 to keep temperatures in the 1.5C scenario (IPCC, 2018). EVs have been shown through lifecycle assessments to be cleaner than combustion vehicles (IPCC, 2018).

It seems that Elon Musk improving the car itself and Climate Change threatening our existence are not enough reasons for EVs to replace all CVs. The transition to EVs is going too slow. Only 8% of the world’s vehicles were electric in 2021 (Xia, 2022). The US can improve their approach on popularizing EVs because other countries have seen more success at increasing EV usage. The US is behind on EV adoption compared to China and Europe, and this means there are better means to electrify cars. Statistics from 2016 to 2020 show that the market share of EVs in Europe and China have increased exponentially, 60% and 36%, respectively (DeSilver,

2021). Meanwhile, the US has stayed relatively linear with an increase of 17% (DeSilver, 2021). In 2020, 10% of Europe, 5.7% of China, and 2% the US's vehicles were electric (DeSilver, 2021). This different levels of success around the world shows that it is important to study the reasons holding back the transition to EVs.

This STS research paper will first widen the field of view on reasons that affect the transition to EVs by presenting an expanded list of factors, based on a popular survey and literature review. This is to provide more options to consider than the most discussed factors. Then, it will narrow the list by applying Everett Roger's theory of Diffusion of Innovation (DOI) and emphasizing the most important factors. "Diffusion is the process by which an innovation is communicated through certain channels over time among the members of a social system (Rogers, 2003). An innovation is an idea, practice, or object perceived as new by an individual or other unit of adoption (Stacks, 2019)." Through the lens of DOI, the new list of options can be narrowed to several key factors. It will help confirm the belief that the most popular factors are the most important, and it will also reveal other factors that need more awareness.

Part I: Factors Affecting the Diffusion of Electric Vehicles

Popular Factors Based on Surveys

Typically, when society thinks about what is required for an individual to buy an EV over a CV, they think of the charging station availability, purchase price, and range (Consumer Report, 2020). These are the big three complaints that people have, and Consumer Reports survey results show they are significantly more reported upon than other reasons (2020). The other reasons were "Don't know enough about EVs to buy one", "Nowhere to charge it at home", "Long charging times", "Lack of model options", "Higher state registration fees", and

“Difficult to use.” Based on this public opinion, this paper will group the big three reasons as the Popular Factors.

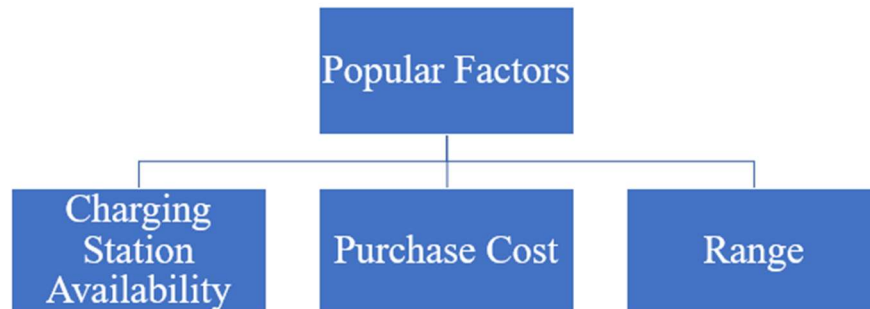


Figure 1 Popular Factors of Deciding to Buy an EV

We should explore more factors than only the popular ones. Tesla, an electric vehicle company, would be satisfied with only focusing on the popular factors. Since Tesla makes charging stations too, they control all 3 of these areas. Having control over the deployment of your own innovation is reassuring. On top of that, businesses that think in optimization and compromises would say it is good enough to address the most pressing complaints. That if they narrow their focus on the popular factors, they use their resources efficiently by not spreading themselves out too thin. There is good reason for the reporting on these popular barriers. These are issues that were prevalent when society was deciding whether their vehicles should be electric, steam, or gasoline. Taalbi’s (2021) study found the following:

Today, in a sense, electric vehicles still face the same obstacles they did some 100 years ago. Bottlenecks to the wider diffusion of electric vehicles still concern infrastructure (charging stations) and appealing to consumers outside the niche market of affluent urban and environmentally aware consumers. These results are similar to current research pointing to the availability of charging stations as the most important determinant of (consumer) adoption rates of electric vehicles. (p. 974)

From a business perspective, charging availability is still a main factor. Studies by the School of Business at University of California Berkeley show that EV companies are dependent on charging station rollout (Anderson, 2022). By increasing the number of charging stations, the demand for EVs increases.

However, as important as the popular factors are in many consumers' minds, I argue it would be limiting to only focus on them. Vehicles are deeply woven into the operations of life and society that the popular factors do not cover other areas of human interaction. Two of the popular factors, range and cost, are dealing with technology such as hardware of the car, manufacturing processes, and supply chains just to begin. Often, we are too quick to blame the technical side, using technocentric phrasing that appear as if the car is an entity on its own. One example of technocentric thought associated with EVs is saying they are the solution to climate change and that fully transitioning from CVs to EVs will reduce emissions. The technology does not stand on its own, "BEVs are technology, technologies have social contexts and social contexts include systemic features and related attitudes and behaviors. Technocentrism distracts from appropriate recognition of this (Morgan, 2020)." This leads to a dangerous separation of the human from the technology. Due to the popular factors being technocentric, this research paper is important for considering a broader range of factors.

List of Factors Based on Frequency of Appearance

Literature reviews on EVs have compiled an expanded list of factors. Table 1 shows Kumar and Alok's research of the most reported factors in academic journals. Their factors come by counting the number of times a topic appeared in research papers during a 10-year period. The table ranks factors by frequency of appearance while also color coding the factor type, which Kumar and Alok did not do. The color coding illustrates that other than marketing

perspectives and environmental perspectives which ranked infrequent, the remaining types were divided.

Rank by Frequency of Appearance	Factor	Factor Type	Summary & Keywords
1	Charging Infrastructure Development	Charging Infrastructure Readiness	Availability and number of charge points
2	Total Cost of Ownership	Economic	Up-front purchase price, electricity costs, maintenance
3	Purchase Based Incentive Policies	Policies and Regulation	Direct subsidy, registration/emission/tax fee exemption.
4	Range Anxiety	Charging Infrastructure Readiness	Worry that miles per charge is not enough for single trip and charging is required
5	Business Model Development	Economic	Business model that is economically sustainable
6	Government Regulations	Policies and Regulation	Government supporting manufacturers, dealerships, fuel suppliers. GHG Standards and fuel economy mandates, carbon tax.
7	Environmental Concern and Awareness	Consumer Perspectives	Consumers have pro-environmental identity. Early adopters are more environmentally conscious.
8	Potential Environmental Benefits	Environmental Perspectives	GHG emission reduction
9	Performance Measures	Vehicle Design and Performance	Driving range, speed, acceleration. City efficiency is better.
10	Psychological Characteristics	Consumer Perspectives	Morals, personal innovativeness, familiarity with EVs
11	Symbolic Attributes	Consumer Perspectives	People's desire to be seen a certain way. Expensive cars are status symbols.
12	Consumer Heterogeneity	Consumer Perspectives	Cars sold to similar demographics. Available cars are similar
13	Use Based Incentive Policies	Policies and Regulation	Convenience with free parking, toll tax exemption, highway lane access. More effective in busy traffic areas.
14	Electricity Load Distribution and Management	Charging Infrastructure Readiness	Charging station power levels, microgrid management, building substations at each charging point
15	Perceived Risks	Consumer Perspectives	Uncertainty and anxiety with maintenance, payback period, repair infrastructure, safety.

16	Battery Cost and Technology	Economic	Lithium-Ion battery manufacturing price, material supply, battery replacement cost, battery lifespan.
17	Vehicle Design and Features	Vehicle Design and Performance	Needs more variation in models, body type, and sizing.
18	Willingness to Pay	Economic	Viewing EVs as personal identity, ability to pay, positive driving experience
19	Electricity Generation Mix	Environmental Perspectives	Grid energy generated should not be from coal
20	Charging Behavior	Charging Infrastructure Readiness	Location of charge points, time to charge, time of day that people charge
21	Marketing Strategies	Marketing Perspectives	Focus marketing on user's convenience, environmental benefits, model information, availability. EV companies must establish trust
22	Dealership Experience	Marketing Perspectives	Product positioning at stores, availability at dealership, reduce waiting period. Profit margins for EVs at dealerships.
23	Charging Infrastructure Resilience	Charging Infrastructure Readiness	Natural disasters disrupting the grid and therefore travel too

Table 1 Factors found from Literature Reviews in order of Number of Appearances (Kumar, 2020)

Kumar’s survey of the current state of EV research shows that the topics of charging infrastructure, total cost of ownership, and purchase-based incentive policies are being studied the most. The scope of view is expanded by being introduced to atypical topics, such as psychological characteristics. Within that, a metric of customers is their personal innovativeness, described as the willingness to try new things (He et al. 2018). They are excited by change, and these consumers keep up with new trends. Another barrier is perceived risk, or “the uncertainty over maintenance and repair infrastructure (Kumar & Alok, 2020).” As evidence of the validity of these factors, consider a US success story such as California. Although the US is worse than China at the percentage of EVs, California is the leading state. California has been an EV success story by having abundant charging stations, incentives like rebates, and regulations on car

manufacturers (DeSilver, 2021). Those are ranked highly on Kumar's factors as 1, 3 and 6 respectively. The ranking's agreement supports Kumar's research.

One factor that was mentioned in the consumer report survey but not directly in Kumar's is the unfamiliarity with EVs. "Don't know enough about EVs to buy one" was the 4th largest factor in Consumer Reports (2020). It could fall under Kumar's Psychological Perspectives or Marketing Strategies, but those were ranked low. It could suggest that this is a problem area that needs more research. According to Pew Research Center which surveyed 13,749 adults ages 18 to 24 about their knowledge of EVs and found that unfamiliarity is an issue (Spencer & Funk, 2021). Furthermore, even with more understanding, people are divided in opinion. 30% of people claimed to be familiar with EVs, and of that group, 53% were in favor of them, while 39% were not. This could be interpreted as even though people claim to understand EVs, there is misinformation being spread. It would also mean that the reality of EVs is divisive. Age is a factor that has not been mentioned yet either. The Pew Research Center's survey did not collect data from older individuals, which may be a major factor. EVs are currently not affordable to young adults, although they potentially could become so in the next decade.

Looking at Kumar's list of factors plus consumer report's additions, if the researchers in the literature review believe these topics are worth studying, that is one testament to their importance. The review determined importance as which topics are studied the most, and that is a simple and quantifiable method. The factors can be analyzed deeper by filtering through the lens of Diffusion of Innovation.

Part II: Diffusion of Innovation

Basics of the Theory of Diffusion of Innovation

The theoretical framework- diffusion of innovation- looks at how people adopt a new technology into their normal behavior (Stacks, 2019). DOI is a social process of communication and innovativeness. It will be useful to connect Kumar's list to DOI, because it shows which factors are important. It will also show how DOI fails to identify important factors.

The definition of diffusion focuses on an innovation being spread via communication mediums such as mass media and individual-level connections (Stacks, 2019). An individual undergoes a process known as the Innovation-Decision process, which is where "an individual passes from first knowledge of a new idea to adoption and confirmation of the innovation (Stacks, 2019)." It's broken into 3 steps: gain information, adopt, and implement. The information step is the first contact, so individuals still have reservations about the innovation. The next step is adoption, which means the individual has gained confidence in the idea of the innovation. Finally, implementation looks like acting on the innovation, which could mean purchasing the device or spreading the word to others and continuing the branch of diffusion.

The other important aspect of DOI is innovativeness. The founder of DOI, Everett Roger, defined innovativeness as a measure of how early someone will adopt an idea (Stacks, 2019). To identify what that looks like, innovativeness is divided into 5 adopter categories: Innovators, Early Adopters, Early Majority, Late Majority, and Laggards.

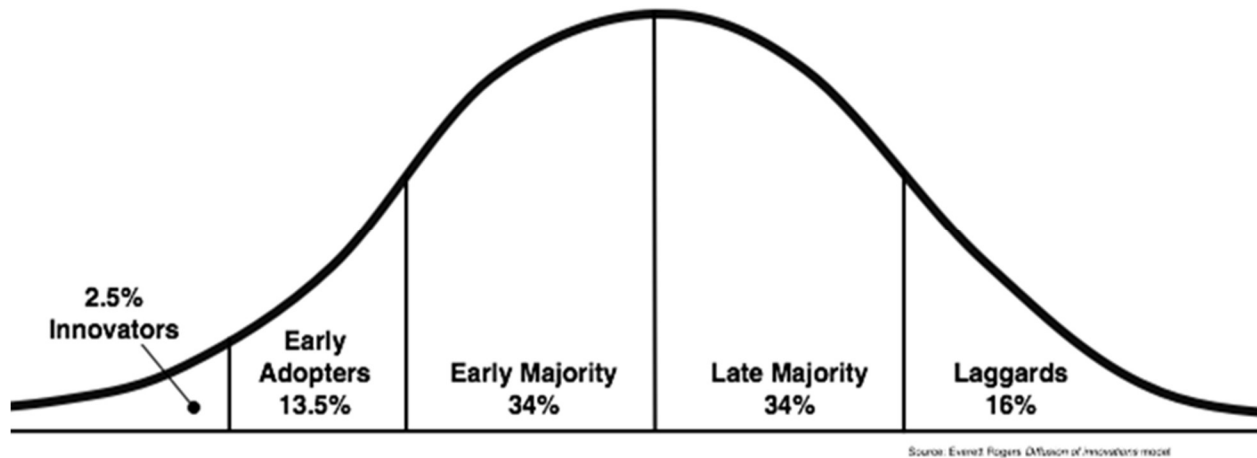


Figure 2 Distribution of Adopter Categories (LaMorte, 2019)

Each adopter category is described by different psychological characteristics. Knowing these characteristics, strategies to appeal to them can be tailored to suit their needs. Innovators do not need much encouragement or incentive (LaMorte, 2019), and since the US's percentage of EVs is higher than 2.5%, EVs have already diffused through this group. Next, early adopters are aware of the need to change and are easy to adopt new idea. They do not need convincing, but they lack the third step of implementation, so they should be given instruction manuals and information sheets. Third, early majority need some convincing to complete the adopting step. They need evidence of success to be convinced (LaMorte, 2019). Fourth, the late majority wants to see that a large group has adopted it successfully. Laggards are conservative and stick to tradition (LaMorte, 2019). They may need statistics, fear appeals, and pressure from people in other groups (LaMorte, 2019). Keeping in mind the characteristics of adopters and the importance of communication, let us evaluate Kumar's list of factors for importance.

Part III: Filtering Factors by Applying Diffusion of Innovation

Factors Based on Diffusion of Innovation

This will present the extent to which DOI is useful in thinking about the diffusion of EVs. The adopter categories allow decision makers such as EV companies, marketers, and policy makers to strategically promote this innovation. The bell curve means most people fall in the early and late majority, so in order to make a dent in transportation emission and convert the most cars to electric, these groups must be appealed to the strongest. Of the two, focusing resources on the early majority would be strategic because the diffusion of EVs has currently progressed to around the beginning of early adopters and there must be momentum to carry through with the early majority. As more individuals adopt and implement EVs, infrastructure builds up that incentivizes it which becomes a positive feedback loop (Stacks, 2019). This is analogous to the diffusion of cell phones because the more people that had cell phones made the innovation more convenient to have (Stacks, 2019). The momentum is important, so it must be enabled now. Since, the early majority is the most important to appeal to currently, they should be applied to the list of factors.

To appeal to the early majority's need of evidence of success, focus should be on EVs effectiveness. The factors that most clearly deal with an effective car are range, charging infrastructure, reducing GHG emissions (potential environmental benefits), perceived risk of maintenance (consumer perspectives), and vehicle performance. Range addresses the main purpose of a car, to get from place to place. Charging infrastructure must allow users to have seamless daily usage. Definitive proof that EVs reduce GHG emissions would clear up skepticism on the environmental benefits of EVs. Maintenance needs proof of success too because EVs are within 10 years of their roll out and full-scale maintenance systems have yet to

come. Vehicle performance is important to show that this car will provide an effective and enjoyable user experience. Other factors have an indirect impact on effectiveness of the car, so I argue that the previous 5 factors are most important currently through the innovativeness lens of DOI.

Using the communication side of DOI, other factors become highlighted. Marketing is key in relaying information about EVs and shaping their image. Symbolic attributes (consumer perspectives) of EVs affect the person-to-person communication because it deals with how people want to be perceived by others. Familiarity with EVs (psychological perspectives) depends on the spread of knowledge about EVs.

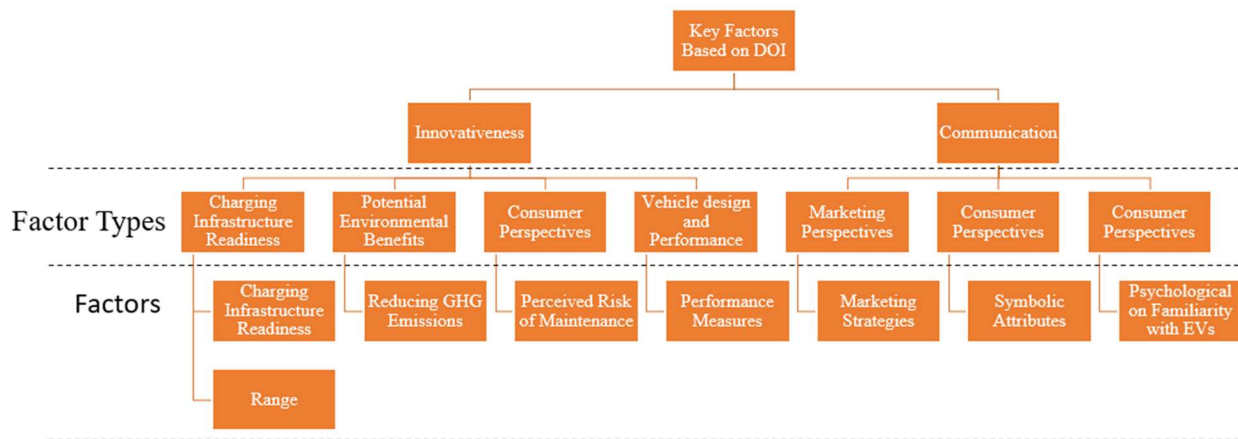


Figure 3 Key Factors Based on DOI

DOI has highlighted 8 of the 23 factors, and 5 of the 7 factor types. Then, looking at the types of the 8 key factors, two of them were charging infrastructure readiness, two consumer perspectives, and the rest were environmental benefits, consumer perspectives, vehicle performance, and marketing. Types that were not mentioned were economics and policies.

The lens of DOI confirms most of the popular beliefs, however, it also highlights other important factors. Compared to the 3 popular factors from the consumer reports survey, two of

the three were also confirmed by DOI. Charging infrastructure and range were important in all three metrics – popular factors, frequency of appearance, and DOI. On the other hand, Cost was not emphasized by DOI. New factors that DOI brought to attention include GHG emissions, maintenance risk, performance, marketing, symbolic attributes, and familiarity with EVs. These factors were not the highest on the frequency of appearances study by Kumar, which means they require more awareness.

DOI's shortcoming is the lack of emphasis on cost. Cost is a dealbreaker for many middle to low-income individuals, and rightfully one of the top 3 factor based off popular factors and frequency of appearance. To neglect cost is to be out-of-touch with reality. However, there is no single framework that is the panacea. Frameworks are useful when they specialize. The point that DOI focuses on areas other than cost is a benefit because it allows researchers to gain a new perspective. To expand this research, it would be recommended to study the other adopter categories. In the near future, as EVs become more diffused, companies will be required switch marketing strategies and appeal to the later categories. Research should reach conclusions before that time has come. Overall, DOI has helped further emphasize popular factors while expanding the scope of view on the transition to EVs.

Conclusion:

The purpose of this research was to question what are the most important factors that affect the transition to EVs. Three metrics were used to evaluate their importance of factors: a popular survey, frequency of appearance in research papers, and the theory of DOI. Instead of taking popular opinion for granted, this research sought out more options through literature reviews and compared the factors using the DOI framework that values communication and innovativeness. Results showed that charging infrastructure and range are key factors regardless.

The third factor, cost, showed different results; cost is often everything in capitalism, and the first two metrics (survey of popular factors and frequency of appearance) agreed that it is one of the most important factors. In spite of that, DOI did not value it. This theory was useful in analyzing factors with a new focus. DOI's focus on innovativeness and communication helped analyze without the shroud of capitalism and finance. This enhanced consideration for social connections and returned attention to person-to-person relationships. This consideration is missing from Elon Musk's technocentric priorities of improving the car itself. Innovation diffuses by social means, so the additional filter of DOI provides a wholistic understanding of important factors.

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