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https://doi.org/10.6028/NIST.DCI.006

NIST NATIONAL INSTITUTE OF STANDARDS AND TECHNOLOGY
U.S. DEPARTMENT OF COMMERCE

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January 2025

U.S. Department of Commerce
Jeremy Pelter, Acting Secretary of Commerce

National Institute of Standards and Technology
Craig Burkhardt, Acting Under Secretary of Commerce for Standards and Technology and Acting NIST Director

NIST DCI 006
January 2025

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NIST Technical Series Publication Identifier Syntax

Publication History
Approved by the NIST Editorial Review Board on 2025-01-27

How to Cite this NIST Technical Series Publication
Gore C, Helgeson JF, Kneifel J (2025) Data Collection Instrument: Consumer Preferences for Battery Electric Vehicles and Battery Information. (National Institute of Standards and Technology, Gaithersburg, MD), NIST Data Collection Instruments (DCI) NIST DCI 006. https://doi.org/10.6028/NIST.DCI.006

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Abstract

This data collection instrument contains example survey questions to evaluate consumer preferences for battery electric vehicles. The survey includes questions about current vehicle ownership, future vehicle decisions, as well as a number of questions related to perceptions and preferences of consumers. There is an additional set of questions aimed at battery electric vehicle owners that include the range of their vehicle as well as driving patterns.

Keywords

Battery electric vehicle; battery information; battery performance; battery lifetime; range anxiety; resale anxiety; survey design.

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1. Introduction

The global shift towards sustainable transportation is gaining momentum, with battery electric vehicles (BEVs) emerging as a promising strategy to reduce greenhouse gas emissions and mitigate climate change. However, the widespread adoption of BEVs is influenced by a complex interplay of factors, including consumer preferences, technological advancements, government policies, and infrastructure development.

Understanding the factors that drive or hinder BEV adoption is critical for policymakers, industry stakeholders, and researchers alike. By identifying the key determinants of BEV purchase decisions, it is possible to tailor policies and strategies to accelerate the transition to electric mobility. This data collection instrument (DCI) aims to provide an overview of a survey design deployed to better understand the factors that influence BEV adoption, drawing on existing research and highlighting emerging trends with a particular emphasis on the batteries of BEVs.

Gore et al. summarize the state of the literature concerning key factors influencing BEV adoption [1]. Several key factors have been identified as significant drivers or barriers to EV adoption and were considered in our development of the DCI described in this publication:

1. Consumer Attitudes and Perceptions:
    - Environmental Concerns: A strong correlation exists between environmental awareness and BEV adoption. Individuals who prioritize sustainability are generally more likely to consider BEVs.
    - Range Anxiety: Concerns about the limited driving range of BEVs can deter potential buyers. However, advancements in battery technology and the expansion of charging infrastructure are gradually alleviating this concern.
    - Perceived Costs: For some consumers, the initial purchase price of EVs, as well as the potential costs of charging and maintenance, can be a significant barrier.
    - Driving Experience: Positive perceptions of BEV performance, handling, and quiet operation can encourage adoption.
2. Technological Advancements:
    - Battery Technology: Improvements in battery capacity, charging speed, and lifespan are crucial for enhancing BEV performance and reducing range anxiety.
    - Vehicle Design and Performance: The availability of a diverse range of BEV models, including sedans, SUVs, and trucks, can appeal to a wider range of consumers.
    - Autonomous Vehicle Technology: The integration of autonomous driving features can further increase the appeal of BEVs.
3. Government Policies and Incentives:

- Purchase Incentives: Subsidies, tax credits, and other financial incentives can significantly reduce the upfront cost of BEVs and stimulate demand.
- Infrastructure Development: Investments in public charging infrastructure, particularly in urban and rural areas, are essential for supporting BEV adoption.
- Emissions Standards and Regulations: Stricter emissions regulations can incentivize the production and sale of BEVs.

4. Infrastructure Development:
    - Charging Infrastructure: The availability of convenient and reliable charging stations is a critical factor for BEV adoption, especially for long-distance travel.
    - Grid Capacity: The increasing number of BEVs requires adequate grid capacity to support charging demand.

The DCI provides a framework for decision science methods to delve deeper into several of these influencing factors, analyzing their impact on BEV adoption and discussing potential implications. By collecting data in this way, we can better understand the complex interplay of these factors within the BEV market, especially for repurchasing of pre-owned BEVs. Collecting primary data on BEV ownership and perceptions supports future research and development in BEV technology and communication of critical information concerning BEV performance.

2. Background

This section will give a brief overview of the literature most relevant to this data collection instrument. The first subsection will focus on drivers and barriers to battery electric vehicle adoption. The second subsection will focus on the total cost of ownership. The final subsection will focus on battery technology and battery-specific information. A more complete literature review can be found in Gore et al. [1].

2.1. Battery Electric Vehicle Adoption

Understanding who is most likely to purchase a BEV and what demographic characteristics are associated with BEV adoption has been widely studied [2–9]. One key factor that has been cited in multiple papers is that concern for the environment is positively associated with stated intentions to adopt a BEV or hybrid vehicle [2, 4, 10]. Another key driver of BEV and hybrid adoption is excitement around technology innovation and the adoption of new technology [5, 11]. The convenience of charging station locations and infrastructure are also vital for increasing BEV adoption [12–14]. Other factors that increase the likelihood of adopting a BEV or hybrid vehicle include previous experience with electric vehicles, concern surrounding dependence on foreign oil, and higher education levels [4]. Additionally, due to the limited range of a BEV and the restrictions the range of a BEV imposes on mobility, Peters and Dütschke find that multi-car households are more likely to purchase a BEV[8]. The consideration of BEV batteries in the adoption literature is predominately focused on the range of the battery [4, 15, 16]. The cost of BEV batteries has not been examined directly, but has been included in the adoption literature in the overall cost of a BEV [2].

2.2. Total Cost of Ownership

BEVs generally are more expensive to purchase than conventional vehicles, but this higher purchase price is partially offset by lower operational costs including fuel cost and maintenance cost [17–21]. Due to the high purchase price of BEVs financial incentives have been widely studied as a way to decrease the cost to the consumer and incentivize the adoption of BEVs [22–24]. Giving consumers information about the total cost of ownership of electric vehicles increases an individual's preference for a BEV or hybrid vehicle, since part of the purchase cost is offset by future savings [18]. The longevity of the batteries in BEVs has been modeled in studies analyzing the total cost of ownership of BEVs [17, 25, 26], but the cost of ownership studies vary widely based on the assumptions [27]. Prior literature exploring the cost of BEVs also varies widely by how long someone is expected to own the vehicle, from three years in Palmer et al. to ten years in Hagman et al. [19, 25]. Letmathe and Suares specifically consider reselling the battery separately from the resale cost of the vehicle when calculating the total cost of ownership [26]. Additionally, Hagman et al. use different depreciation rates for BEVs, which could partially capture the decrease in battery capacity over time [25].

2.3. Battery Technology

The batteries of BEVs come with new risks for the automotive industry and consumers. Christensen et al. examine the risks associated with batteries including the disposal of batteries, recycling, accidents, and the potential to reuse batteries as an energy storage system [28]. An increase in education and legal processes is needed to address the safety risks associated with BEV adoption [28]. In a series of in-depth interviews Pedrosa and Nobre find that risks associated with the battery of an electric vehicle are a major barrier to second-hand electric vehicle adoption [29]. Since BEV batteries are so expensive to replace, and many consumers will notice the impact due to the range decrease of the vehicle, consumers are more likely to purchase a used BEV if it has a new battery than with the original battery [29].

Battery technology has recently undergone a rapid transformation. The design of a BEV battery takes into account the temperature range that the BEV operates and the safety , lifetime, and weight of the battery while trying to increase energy density and decrease charging time [30] Bashash et al. calculate the optimal charging pattern of electric vehicles, while balancing the cost of charging and the health and longevity of the battery [31]. Battery health is highly dependent on charging frequency and driving patterns [31, 32]. The climate that the vehicle is driven in is also a large driver of BEV battery longevity with estimates ranging from five years to thirteen years depending on the climate [33]. Martel et al. 2017 find the battery should be replaced preemptively to avoid an increase in fuel costs and energy usage as the battery capacity declines, while Neubauer et al. find that due to the cost of replacement, the battery of a BEV is never replaced [34, 35].

Due to the resource intensive nature of BEV batteries, it is extremely important to consider options for reusing and recycling BEV batteries. Baars et al. examine technology and policy driven reduction and recycling scenarios for BEV adoption and find more ambitious circular economy strategies are necessary to deal with the resource challenges associated with BEV batteries [36]. Skeete et al. highlight the importance of setting up a system to reuse or recycle BEV batteries now due to the age of some BEVs on the road [37]. Financial incentives can be used to incentivize repurposing of BEV batteries into energy storage systems to peak-shift energy needs and reduce greenhouse gas emissions [38]. Additionally, repurposing BEV batteries at the end of their life could lower the cost differential between BEVs and conventional vehicles [39].

3. Survey Instrument

This survey instrument can be generalized to be utilized for other household vehicle surveys. The survey described below was adapted from several prior household vehicle surveys including Gore and Carrel et al. [10, 11]. Additional questions were designed specifically to target the information needs of consumers of used electric vehicles, specifically related to the electric vehicle batteries.

3.1. Survey Consent

The first question within the survey was to obtain informed consent. The whole language from the question and the options individuals could select are included below.

Welcome!

We thank you very much for participating in this survey. The purpose of this study is to understand what people look for in their vehicle purchases. This survey should take about 10-15 minutes to complete.

This survey will focus on the passenger vehicles that your household owns, which does not include motorcycles. Your household includes all the persons who occupy the housing unit as their usual place of residence.

In order to participate in this research please review the Consent to participate in research document and indicate whether you consent to participating. This information can be found at this link: Household vehicle survey information sheet

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Expiration Date 9/30/2024

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- *I consent*
- *I do not consent*

3.2. Survey Sections

The survey instrument includes fourteen main sections with some sections only containing one question: (1) screening demographics, (2) vehicle ownership questions, (3) BEV specific questions, (4) behavioral questions of BEV owners, (5) screening questions for non-BEV owners, (6) questions about next vehicle, (7) driving patterns, (8) BEV knowledge, (9) attention checks, (10) expectations, (11) information for decision making process, (12) perceptions of risks of BEV ownership, (13) demographics, and (14) open ended response.

3.2.1. Screening Demographics

The first section of the survey includes two demographic questions. The first question is to measure the age of participants and anyone under the age of eighteen was excluded from the survey. The second question is to get a ratio of men and women taking the survey and no participants were excluded for their answer to the question or for skipping the question.

How old are you?

- *Under 18*
- *18 - 19*
- *20 - 24*
- *25 - 29*
- *30 - 34*
- *35 - 39*
- *40 - 44*
- *45 - 49*
- *50 - 54*
- *55 - 59*
- *60 - 64*
- *65 - 69*
- *70 - 74*
- *75 - 79*
- *80 - 84*
- *Over 85*

What is your sex? If you would prefer to not answer this question, please skip to the next question.

- *Male*
- *Female*

3.2.2. Vehicle Ownership Questions

The second section of the survey asks about the number of vehicles owned by the household as well as some basic information about each vehicle in the household. Participants saw the same three questions for each vehicle they owned. If a participant owned two vehicles, then they would first answer questions about the body style, fuel type, and ownership of their first vehicle and then they would be presented with the same three questions to answer about their second vehicle. The text that is bolded and underlined changed for each question to indicate if individuals should be answering about their first, second, third, fourth, or fifth vehicle. If a participant indicated that they owned six or more vehicles, then they would answer the questions about their first five vehicles only.

How many passenger vehicles (not including motorcycles) are in use by your household? Your household includes all the persons who occupy the housing unit as their usual place of residence.

- *0*
- *1*
- *2*
- *3*
- *4*
- *5*
- *6 or more*

*Please answer the following questions for the **first** vehicle in your household.*
Considering the body style of the vehicle, what type of vehicle do you and others in your household own or lease right now?

- *Coupe or hatchback*
- *Sedan*
- *Small SUV (two rows of seats)*
- *SUV (three rows of seats)*
- *Minivan or van*
- *Truck*

*Considering the fuel type (or equivalent) of the vehicle, what type of vehicle do you and others in your household own or lease right now? Please answer about the **first** vehicle in your household.*

- *Gasoline*
- *Diesel*
- *Battery Electric Vehicle (BEV)*
- *Hybrid*
- *Plug in hybrid*
- *Other _____*

*Do you lease or own this vehicle? Please answer about the **first** vehicle in your household.*

- *Own*
- *Lease*
- *Other _____*

3.2.3. BEV Specific Questions

Since this survey is aimed at understanding battery related characteristics and degradation of battery lifetime of BEVs, there is an additional section of questions that were answered by anyone who indicated that they owned a BEV. Participants were first asked what year their BEV was made. Then the make and model information were obtained. The make was asked first, and depending on the make, the model question was different to include a subset of all potential models, since the full set of models available is a long list. All lists were sorted into alphabetic order to make it easier for participants to find the make or model of their vehicle. The make and model also serve as a robustness check to ensure that participants who indicated

they have a BEV have a BEV. Data in the analysis is not used for people who indicated they have a BEV but did not select an accurate make and model match. For example, if someone selected that they owned a Toyota Model 3 that would not be a make and model match since the maker of the Model 3 is Tesla and not Toyota. Since the trim level can impact the range of a BEV significantly, we also include an open-ended question about the trim level. This question was not required, however, since it is likely that some BEV owners do not have a trim level or might not remember the trim level of their vehicle. We also asked about the estimated range of the vehicle at the time of purchase as well as the current estimated range. However, this data is likely to have measurement errors in the reported values, so it should be used cautiously. Additionally, we ask about the number of miles on the vehicle.

The survey also asks if the vehicle was purchased new or used. If the vehicle was purchased used, then a few additional questions, including how old the vehicle was when it was purchased and the number of miles on the vehicle when it was purchased are also included. While there are not many BEVs that have been purchased on the used vehicle market, increasingly more vehicles are purchased second hand.

The survey then asks several questions related to the charging behavior of the BEV. Charging has a large impact on a number of different BEV related attributes, including battery degradation and the environmental footprint of the vehicle. The questions include the frequency of charging, type of charging, time of charging, and more.

Then the survey asks participants what their primary reason for purchasing a BEV was from the following options: to save money on gasoline, to reduce trips to the gas station, to have a technologically innovative vehicle, to reduce their environmental footprint, or other with the option to explain the primary reason. The survey then includes a few questions about the driving behavior while using the BEV, since driving behavior can impact the battery longevity and performance.

What year was your battery electric vehicle (BEV) produced?

- *2007 or earlier*
- *2008*
- *2009*
- *2010*
- *2011*
- *2012*
- *2013*
- *2014*
- *2015*
- *2016*
- *2017*
- *2018*
- *2019*
- *2020*
- *2021*
- *2022*
- *2023*
- *2024 or later*

*What is the **make** of your BEV?*

- *Aston Martin*
- *Audi*
- *BMW*
- *Chevrolet*
- *Coda*
- *Fisker*
- *Fiat*
- *Ford*
- *Genesis*
- *GMC (General Motors)*
- *Honda*
- *Hyundai*
- *Jaguar*
- *Kia*
- *Lexus*
- *Lotus*
- *Lucid Motors*
- *Maserati*
- *Mazda*
- *Mercedes-Benz*
- *Mini Cooper*
- *Mitsubishi*
- *Nissan*
- *Polestar*
- *Porsche*
- *Rivian*
- *Subaru*

- *Smart*
- *Tesla*
- *Toyota*
- *Vinfast*
- *Volkswagen*
- *Volvo*
- *Other _____*

*What is the **model** of your BEV?*

- *Blazer EV*
- *Bolt EV*
- *Bolt EUV*
- *e-tron*
- *e-tron GT*
- *e-tron Sportback*
- *i3*
- *i4*
- *i5*
- *i7*
- *iX xDrive45*
- *Lagonda*
- *Q4 e-tron*
- *Q4 e-tron Sportsback*
- *Q6 e-tron*
- *S-10 Electric*
- *Spark EV*
- *Other _____*

*What is the **model** of your BEV?*

- *500e*
- *Coda*
- *E-Transit*
- *Electrified G80*
- *Electrified GV70*
- *EV1*
- *F-150 Lightning*
- *Focus Electric*
- *Hummer EV*
- *Mustang Mach-E*
- *Ocean*
- *Ranger EV*
- *Other _____*

*What is the **model** of your BEV?*

- *Air*
- *Clarity BEV*
- *EV6*
- *EV9*

- *Fit EV*
- *Gravity*
- *I-PACE*
- *IONIQ 5*
- *IONIQ 6*
- *IONIQ Electric*
- *Kona Electric*
- *Niro EV*
- *RZ*
- *Soul EV*
- *Type 133*
- *Other _____*

*What is the **model** of your BEV?*

- *Ariya*
- *2*
- *3*
- *4*
- *B250e*
- *Electric SE Hardtop 2 door*
- *EQB*
- *EQB 250+*
- *EQE*
- *EQS*
- *EQS SUV*
- *GranTurismo*
- *iMiEV*
- *LEAF*
- *MX-30*
- *R1S*
- *R1T*
- *Taycan*
- *Other _____*

*What is the **model** of your BEV?*

- *bZ4x*
- *C40*
- *e-Golf*
- *EX90*
- *Fortwo*
- *ID.4*
- *Model 3*
- *Model S*
- *Model X*
- *Model Y*
- *RAV4 EV*
- *Roadster*
- *Solterra*

- *VF9*
- *XC40 Recharge*
- *Other _____*

*What is the **trim level** of your BEV? The trim level refers to different pre-packaged groups of features of a vehicle.*

_____

*What was the **manufacturer rated range** of your BEV when you purchased it? An approximate value is fine.*

_____

As of today, approximately how many miles are on your BEV?

- *0 - 9,999*
- *10,000 - 19,999*
- *20,000 - 29,999*
- *30,000 – 39,999*
- *40,000 – 49,999*
- *50,000 – 59,999*
- *60,000 – 69,999*
- *70,000 – 79,999*
- *80,000 – 89,999*
- *90,000 – 99,999*
- *100,000 – 109,999*
- *110,000 – 119,999*
- *120,000 – 129,999*
- *130,000 – 139,999*
- *140,000 – 149,999*
- *150,000 – 159,999*
- *160,000 – 169,999*
- *170,000 – 179,999*
- *180,000 – 189,999*
- *190,000 – 199,999*
- *200,000 or more*

*What is the **current range** of your BEV when fully charged? An approximate value is fine.*

_____

Was your BEV new or pre-owned when you purchased or leased it?

- *New*
- *Pre-owned*
- *Other _____*

How old was your BEV when you purchased it?

- *Less than 1 year*
- *1 year*
- *2 years*
- *3 years*
- *4 years*
- *5 years*
- *6 years*
- *7 or more years*

How many miles were on your BEV when you purchased it?

- *0 - 9,999*
- *10,000 - 19,999*
- *20,000 - 29,999*
- *30,000 - 39,999*
- *40,000 - 49,999*
- *50,000 - 59,999*
- *60,000 - 69,999*
- *70,000 - 79,999*
- *80,000 - 89,999*
- *90,000 - 99,999*
- *100,000 or more*

How often do you charge your BEV?

- *1 time a day*
- *6 times a week*
- *5 times a week*
- *4 times a week*
- *3 times a week*
- *2 times a week*
- *1 time a week*
- *Less than one time a week*

Where do you charge your BEV most often?

- *At home*
- *At a work provided charging station*
- *At a public charging station*

What time of day do you typically charge your BEV?

- *In the mornings*
- *In the middle of the day*
- *In the evenings*
- *Overnight*

How long do you typically charge your BEV?

- *Less than one hour*
- *1-2 hours*
- *2-3 hours*
- *3-4 hours*
- *4-5 hours*
- *5-6 hours*
- *6-7 hours*
- *7-8 hours*
- *More than 8 hours*

Do you typically unplug your BEV once it is fully charged?

- *Yes, most of the time*
- *Yes, some of the time*
- *Yes, but rarely*
- *No, never*

At your residence what type of charging do you use?

- *Level 1 (120 volts from a standard outlet)*
- *Level 2 (240 volts)*
- *Level 3 (Supercharger or DCFC)*
- *Do not charge at my residence*

Did you pay for the installation of a home charger?

- *Yes*
- *No*
- *I do not have a home charger*

*How often do you use a **level 3 fast charger** (DC Fast Charging or Supercharging) to charge your BEV?*

- *Once a week or more*
- *Twice a month*
- *Once a month*
- *Every other month*
- *Every 6 months*
- *Once a year or less*
- *Never*

What was your primary reason for purchasing a BEV?

- *To save money on gasoline*
- *To reduce trips to the gas station*
- *To have a technologically innovative vehicle*
- *To reduce my environmental footprint*
- *Other _____*

*In the last year, approximately how many times did your household use your BEV for a trip that took **more than 2.5 hours one direction**?*

- *Never*
- *1-3 times*
- *4-6 times*
- *7-9 times*
- *9-11 times*
- *12 or more times*

*What percent of your household's time spent driving the BEV is **on an interstate or highway**? Please consider all time spent driving the BEV by your household.*

- *Less than 25%*
- *25% to 49%*
- *50% to 74%*
- *75% or more*

*What percent of your household's time spent driving the BEV is **in stop and go traffic**? Please consider all time spent driving the BEV by your household.*

- *Less than 25%*
- *25% to 49%*
- *50% to 74%*
- *75% or more*

*What percent of your household's time spent driving the BEV is on **roads with a stop sign or traffic light within every 2-3 minutes of driving**? Please consider all time spent driving the BEV by your household.*

- *Less than 25%*
- *25% to 49%*
- *50% to 74%*
- *75% or more*

How would you describe your household's driving style when driving the BEV?

- *Very aggressive*
- *Aggressive*
- *Slightly aggressive*
- *Neutral*
- *Slightly passive*
- *Passive*
- *Very passive*

3.2.4. Screening Questions for non-BEV Owners

For the general population sample, we wanted to ensure that participants had recently purchased a vehicle or were planning to purchase a vehicle in the future to indicate that they had some familiarity with the process of buying a vehicle. In order to ensure that they had this familiarity, we use two questions: one that asks about the last time the participant purchased a vehicle and one that asks about the next time a participant plans to purchase a vehicle.

When was the last time you purchased a new or pre-owned vehicle?

- *Within the last year*
- *1-2 years*
- *2-3 years*
- *3-4 years*
- *4-5 years*
- *5 or more years*
- *Never*

Do you plan to purchase or lease a new or pre-owned vehicle in the next:
If you are unsure, please give us your best guess.

- *1 year*
- *2 years*
- *3 years*
- *4 years*
- *5 years*
- *6 years*
- *7 years*
- *8 years*
- *9 years*
- *10 years*
- *More than 10 years*
- *Do not plan to purchase a new or pre-owned vehicle in the future*

3.2.5. Questions about Next Vehicle

The next section of the survey focused on the participants' expectations about their next vehicle purchase. The questions include the intended duration of ownership for their next vehicle, if they plan to purchase or lease, if they plan to buy a new or pre-owned vehicle, as well as the fuel type of vehicle the next vehicle will replace. The next question asked is aimed at understanding the individual's likelihood of purchasing a BEV as their next vehicle. The next two questions are controls for if a BEV would fit easily into someone's current lifestyle, which includes if they currently have access to a plug where they park their vehicle and how often they make a trip that could be outside of the range of a typical BEV.

*When you purchase or lease a new or pre-owned vehicle, how **many years do you intend to keep that vehicle** before replacing it? If you are unsure, please give us your best guess.*

- *Less than 1*
- *1*
- *2*
- *3*
- *4*
- *5*
- *6*
- *7*
- *8*
- *9*
- *10*
- *11*
- *12*
- *13*
- *14*
- *15*
- *16*
- *17*
- *18*
- *19*
- *20*
- *more than 20*

*Which most accurately describes your **next** choice of vehicle?*

- *Purchase new vehicle*
- *Lease new vehicle*
- *Purchase a pre-owned vehicle less than 5 years old*
- *Purchase a pre-owned vehicle more than 5 years old*
- *I am unsure*
- *Other _____*

*For the vehicle your household **plans to replace**, what is the fuel type (or equivalent)?*

- *The new or pre-owned vehicle will not replace any other vehicle*
- *Gasoline*
- *Diesel*
- *BEV*
- *Hybrid*
- *Plug in Hybrid*
- *Other _____*

Many of the following questions ask about battery electric vehicles.

*• A **battery electric vehicle (BEV)** is an all-electric vehicle powered by plugging into a specialized outlet and using electricity to charge a battery pack, with no gasoline engine. A Tesla Model 3 is an example of a BEV. A*

BEV cannot drive without being charged.
*• A **hybrid vehicle** is a vehicle that uses gasoline and battery power, but does not plug in to charge. A hybrid's battery is re-charged by driving the vehicle. A Toyota Prius is an example of a hybrid vehicle.*
*• A **plug-in hybrid** vehicle is a vehicle that uses gasoline and battery power that can be plugged in to charge the battery. The Chevy Bolt is an example of a plug-in hybrid vehicle.*

We will also ask several questions about your knowledge of vehicles and related items. Please do not look up answers to these questions, we want to know your best guess.

*Think about your household's **next** vehicle choice. How likely are you to select a BEV (Battery Electric Vehicle)?*

- *Extremely unlikely*
- *Moderately unlikely*
- *Slightly unlikely*
- *Neither likely nor unlikely*
- *Slightly likely*
- *Moderately likely*
- *Extremely likely*

Do you have access to an electrical outlet where your vehicle is parked at your primary residence?

- *Yes*
- *No*
- *Unsure*

*Consider how frequently your household uses a vehicle for long trips. In the last year, including work-related trips, weekends, holidays and vacations, approximately how many times did you use your own vehicle for a trip that took **more than 2.5 hours one direction**?*

- *Never*
- *1-3 times*
- *4-6 times*
- *7-9 times*
- *9-11 times*
- *12 or more times*

3.2.6. BEV Knowledge

The next section of the survey includes two questions aimed at understanding how much the individual knows about a BEV. The first question is an open-ended response box that asks participants how many miles they believe a fully charged BEV can be driven. The second question asks participants how long they believe it takes to charge a BEV from 20% of capacity to full capacity.

Approximately how many miles do you believe a fully charged BEV can be driven before the battery is drained?

_____

*How long do you think it takes to charge a BEV battery from 20% capacity to **full** using a standard outlet?*

- *Less than 30 minutes*
- *30 minutes to 1 hour*
- *1 hour to 2 hours*
- *2 hours to 4 hours*
- *4 hours to 8 hours*
- *Over 8 hours*

3.2.7. Attention Checks

The survey also included two attention checks to ensure that participants were reading each question. The first attention check question was a true or false question stating the current yearwas 2019, and the correct answer was false since the survey was deployed in 2023. The first question appeared around halfway through the survey. The second attention check appears towards the end of the survey. The second attention check question was embedded in a matrix of other questions and asked respondents to select strongly disagree as the answer to that question. In surveys that take longer than 10 minutes to complete, it is best practice to include attention checks to ensure data quality. Additionally, if there are multiple matrices of questions in the survey, it is best to include one matrix-based attention check.

The year is 2019

- *True*
- *False*

Please indicate the extent to which you agree or disagree with the following statements.

	Strongly disagree	*Disagree*	*Somewhat disagree*	*Neither agree nor disagree*	*Somewhat agree*	*Agree*	*Strongly agree*
Please select "strongly disagree" as your response to this item	○	○	○	○	○	○	○

3.2.8. Expectations

Since individual's expectations about future costs and comparisons between alternatives shape their decision making, the survey also contains a section on perceptions and expectations. This set of questions includes how individuals perceive the annual fuel costs and the total cost of ownership of a BEV compare to that of a conventional gasoline vehicle. There are also a few questions about how they expect gasoline prices, battery prices, and vehicle purchase prices to

change in the next 5 years. Additionally, there are two questions about the battery, specifically about a BEV to gain some knowledge about the participants' awareness of battery technology.

*Compared to the annual fuel cost for a gasoline vehicle of the same type and size, do you think the **annual cost of electricity** for a BEV is:*

- *Much less (more than 50% lower)*
- *Somewhat less*
- *About the same*
- *Somewhat more*
- *Much more (more than 50% higher)*

Total Cost of Ownership includes financing, vehicle depreciation (loss in value), insurance premiums and fees, fuel-equivalent costs (either electricity or gasoline), repair and maintenance costs.

*Compared to a gasoline vehicle of the same type and size, do you think the **Total Cost of Ownership** of a BEV over five years would be:*

- *Much less (more than 50% lower)*
- *Somewhat less*
- *About the same*
- *Somewhat more*
- *Much more (more than 50% higher)*

*How do you expect **gasoline prices** to change in the next 5 years?*

- *Much less (more than 50% lower)*
- *Somewhat less*
- *About the same*
- *Somewhat more*
- *Much more (more than 50% higher)*

*How do you expect **BEV battery prices** to change in the next 5 years?*

- *Much less (more than 50% lower)*
- *Somewhat less*
- *About the same*
- *Somewhat more*
- *Much more (more than 50% higher)*

*How do you expect **BEV purchase prices** to change the next 5 years?*

- *Much less (more than 50% lower)*
- *Somewhat less*
- *About the same*
- *Somewhat more*
- *Much more (more than 50% higher)*

*How do you expect **new gasoline vehicle purchase prices** to change the next 5 years?*

- *Much less (more than 50% lower)*
- *Somewhat less*
- *About the same*
- *Somewhat more*
- *Much more (more than 50% higher)*

*How do you expect **pre-owned gasoline vehicle purchase prices** to change the next 5 years?*

- *Much less (more than 50% lower)*
- *Somewhat less*
- *About the same*
- *Somewhat more*
- *Much more (more than 50% higher)*

How many years do you expect the battery of a new BEV to last before you must replace the battery? Please only use whole numbers.

_____

How much do you think replacing a BEV battery costs (including the cost of the battery and labor to install the battery)? Please only use whole numbers.

_____

3.2.9. Information for Decision Making Process

The next section of the survey measures the type and source of information that would be useful to participants in the decision-making process of buying a pre-owned battery electric vehicle. The health and longevity of the battery of a BEV is an extremely important component of a pre-owned BEV due to the vehicle's dependence on the battery. Participants were asked how useful or unuseful knowing the expected lifetime, expected range for a certain number of years, and current vehicle range is when purchasing a pre-owned BEV. The participants were also asked how useful different sources of information, including a general guarantee, manufacturer warranty, federal rating, and industry rating, would be in their decision-making process.

*What type of information would be useful in your decision-making process to buy a **pre-owned** BEV?*

	Extremely unuseful	*Moderately unuseful*	*Slightly unuseful*	*Neither useful nor unuseful*	*Slightly useful*	*Moderately useful*	*Extremely useful*
Expected remaining lifetime of the battery	○	○	○	○	○	○	○
Expected remaining driving range of the battery for a specific number of years	○	○	○	○	○	○	○
Current remaining driving range of the vehicle	○	○	○	○	○	○	○

*What source of information would be useful in your decision-making process to buy a **pre-owned** BEV?*

	Extremely unuseful	*Moderately unuseful*	*Slightly unuseful*	*Neither useful nor unuseful*	*Slightly useful*	*Moderately useful*	*Extremely useful*
The battery is guaranteed to last for a specific number of years	○	○	○	○	○	○	○
The battery is federally rated to last for a specific number of years	○	○	○	○	○	○	○
The battery is under manufacturer warranty for a specific number of years	○	○	○	○	○	○	○
The battery is industry rated to last for a specific number of years	○	○	○	○	○	○	○

3.2.10. Perceptions of Risks of BEV Ownership

One of the most discussed barriers to BEV adoption is range anxiety. Range anxiety is measured in this survey as a construct with three different statements that can be used together to estimate the latent variable. Additionally, we wanted to measure if anxiety surrounding reselling a BEV was also a barrier to adoption. For resale anxiety, we developed two different sets of questions, one that focuses on a new BEV and one that focuses on a pre-owned BEV. Participants in our survey only saw one of the two sets of questions, but one of the questions was designed to allow comparisons across the randomization of the two sets of questions.

Please indicate the extent to which you agree or disagree with the following statements.

	Strongly disagree	*Disagree*	*Somewhat disagree*	*Neither agree nor disagree*	*Somewhat agree*	*Agree*	*Strongly agree*
If I owned a BEV, I would often worry about running out of charge	○	○	○	○	○	○	○
If I owned a BEV, I would worry about finding places to charge it if I wanted to drive somewhere new	○	○	○	○	○	○	○
Range is a major disadvantage of owning a BEV	○	○	○	○	○	○	○

Please indicate the extent to which you agree or disagree with the following statements.

	Strongly disagree	*Disagree*	*Somewhat disagree*	*Neither agree nor disagree*	*Somewhat agree*	*Agree*	*Strongly agree*
*If I bought a **new** BEV, I would worry that I would not get a good price when I wanted to sell it*	○	○	○	○	○	○	○
BEVs are less valuable than gasoline cars on the resale market, because the technology is always advancing	○	○	○	○	○	○	○
*If I bought a **new** BEV, I would worry about fast depreciation because of battery technology (relative to gasoline vehicles)*	○	○	○	○	○	○	○

Please indicate the extent to which you agree or disagree with the following statements.

	Strongly disagree	*Disagree*	*Somewhat disagree*	*Neither agree nor disagree*	*Somewhat agree*	*Agree*	*Strongly agree*
*If I bought a **pre-owned** BEV, I would worry that I would not get a good price when I wanted to sell it*	○	○	○	○	○	○	○
BEVs are less valuable than gasoline cars on the resale market, because the technology is always advancing	○	○	○	○	○	○	○
*If I bought a **pre-owned** BEV, I would worry about fast depreciation because of battery technology (relative to gasoline vehicles)*	○	○	○	○	○	○	○

3.2.11. Demographics

The final section of the survey is the demographic questions. The first question is to measure the risk aversion of individuals and is adapted from Dohmen et al. 2011 [40]. Additionally, the survey included questions about the type of residence, ownership of the residence, and

whether the residence has solar panels. Measures of income, household size, race, ethnicity, and educational attainment are included. The survey also includes a question about the participants views on the impacts of climate change.

How do you see yourself: Are you generally a person who is fully prepared to take risks or do you try to avoid taking risks? Please answer in general – these can be risks in any realm of your life.

	Avoid Risk 1	2	3	4	5	6	7	8	9	*Risk Taking* 10
1	○	○	○	○	○	○	○	○	○	○

How would you describe your residence?

- *Single family home (detached or free-standing residence)*
- *Multi-family home (apartment, condo)*
- *Duplex, triplex-, or 4-plex*
- *Townhouse*
- *Mobile home*
- *Other*

Do you own or rent this residence?

- *Own*
- *Rent*
- *Other* _____

Do you have solar panels installed on your residence?

- *No*
- *Yes*

Do you own or lease your solar panels?

- *Lease*
- *Own*
- *Other* _____

*What is your annual **household** income?*

- *Less than $10,000*
- *$10,000 to $19,999*
- *$20,000 to $29,999*
- *$30,000 to $39,999*
- *$40,000 to $49,999*
- *$50,000 to $59,999*
- *$60,000 to $69,999*
- *$70,000 to $79,999*
- *$80,000 to $89,999*
- *$90,000 to $99,999*
- *$100,000 to $109,999*
- *$110,000 to $119,999*
- *$120,000 to $129,999*
- *$130,000 to $139,999*
- *$140,000 to $149,999*
- *$150,000 to $159,999*
- *$160,000 to $169,999*
- *$170,000 to $179,999*
- *$180,000 to $189,999*
- *$190,000 to $199,999*
- *$200,000 to $209,999*
- *$210,000 to $219,999*
- *$220,000 to $229,999*
- *$230,000 to $239,999*
- *$240,000 to $249,999*
- *$250,000 or more*
- *Prefer not to answer*

Including yourself, how many people live in your household?

- *1*
- *2*
- *3*
- *4*
- *5*
- *6 or more*

Including yourself, how many people in your household drive a vehicle?

- *1*
- *2*
- *3*
- *4*
- *5*
- *6 or more*

What is your zip code?

_____

What is your race? Please check all that apply.

- *White*
- *Black or African American*
- *Native American or Alaska Native*
- *Asian (including Asian Indian)*
- *Native Hawaiian or Pacific Islander*

Are you Hispanic, Latino, or Spanish in origin?

- *No, not of Hispanic, Latino, or Spanish origin*
- *Yes, Mexican, Mexican Am., Chicano*
- *Yes, Puerto Rican*
- *Yes, Cuban*
- *Yes, another Hispanic, Latino, or Spanish origin*

Please indicate your highest level of education (include degree you are currently working on if applicable)

- *Some high school*
- *High school*
- *GED*
- *Some college*
- *Associate's degree (2-year degree)*
- *4-year college degree*
- *Masters degree*
- *Doctoral degree / advanced degree*
- *Other* _____

How much do you, personally, worry about the issue of global climate change?

- *None at all*
- *A little*
- *A moderate amount*
- *A lot*
- *A great deal*

3.2.12. Open Ended Response

Additionally, we include one open ended, optional question at the end of the survey to allow respondents a way to express opinions that we did not ask specific questions about.

What is the largest concern you have about purchasing a battery electric vehicle?

_____

4. Survey Approvals and Data Collection

Prior to distributing the survey, the survey went through a pilot testing stage and then approvals. In the pilot testing stage, colleagues, including social scientists, planners, and engineers gave feedback on the clarity of questions, flow of the survey, as well as length of the survey. There were a few changes made to the instrument to add information for greater context following the pilot testing stage. Additionally, a few owners of BEVs reviewed the survey for the specific subsections of the survey that related to battery electric vehicles. Pretesting is an important stage of the survey design process to collect feedback and incorporate changes before the design is finalized. It is also helpful to test the length of the survey, because different questions may take more or less time for participants to answer than expected. Thus, having real responses to gauge the true survey administration time is invaluable.

The survey approval process at NIST includes two approvals; the timing of these approvals is not required to be sequential and can be run in parallel. The first is the Institutional Review Board (IRB), which safeguards all human subject welfare in human subjects' research including surveys and questionnaires. The IRB reference number for this data collection at NIST is #EL-2022-0397. The second approval process is the Paperwork Reduction Act (PRA), which requires the approval of any government agency to collect data through a survey to ensure that there is no undue burden placed on individuals. The Office of Management and Budget (OMB) oversees the approval process, and the PRA approval number for this data collectionis 0693-0089.

The data for this survey was collected using a third-party data collection company to recruit and remunerate participants in the data collection. The data collection occurred from March to June of 2023. The final sample included 1490 completed responses, which included 490 battery electric vehicle owners.

5. Summary and Future Efforts

At the time of writing, BEV adoption in the United States is steadily increasing, though still represents a small portion of the overall automobile market. BEVs captured around 8% of the US auto market in Q2 2024, a significant increase from previous years [41]. There is growing consumer interest in EVs, in general, driven by factors like environmental concerns, lower operating costs, and improved vehicle performance. Battery technology is improving, addressing range anxiety and reducing charging times [1]. Federal and state incentives, along with investments in charging infrastructure, are boosting EV adoption. Yet, challenges remain, such as limited charging infrastructure in certain areas and higher upfront costs compared to traditional gasoline vehicles.

While significant progress has been made, widespread BEV adoption will likely take several more years; however, the trend is positive, and the EV market continues to expand. Infrastructure plays a pivotal role in the adoption of electric vehicles (EVs) in the United States. A robust charging infrastructure is essential to alleviate range anxiety and encourage wider EV adoption.

As the researchers undertake the next phase of research on BEV adoption and the potential for improved measurement science to inform communication to the public, this DCI provides critical areas of continued research to best understand consumers' decision-making considerations. Future iterations might include choice experiments structured to better understand preferences within the context of BEV adoption, especially in preowned vehicle markets. Future uses of this DCI might leverage modules of the DCI with new modules focused on emerging concerns in the BEV markets. For example, the danger of fire in BEVs is generally lower than that of traditional gasoline-powered vehicles. Yet, specific circumstances, particularly extreme weather events (e.g., flooding, extreme heat, extreme cold), can increase the risk in hazard-specific ways. Thus, an additional understanding of the regional differences in concerns in the context of the extreme weather expected in those regions is one potential area of additional research in this space.

References

[1] Gore C (2024) Consumer Perspectives on Battery Electric Vehicles: A Literature Review. (National Institute of Standards and Technology, Gaithersburg, MD), NIST TN 2306, p NIST TN 2306. https://doi.org/10.6028/NIST.TN.2306

[2] Axsen J, Kurani KS (2013) Hybrid, plug-in hybrid, or electric-What do car buyers want? *Energy Policy* 61. https://doi.org/10.1016/j.enpol.2013.05.122

[3] Axsen J, Bailey J, Castro MA (2015) Preference and lifestyle heterogeneity among potential plug-in electric vehicle buyers. *Energy Economics* 50. https://doi.org/10.1016/j.eneco.2015.05.003

[4] Carley S, Krause RM, Lane BW, Graham JD (2013) Intent to purchase a plug-in electric vehicle: A survey of early impressions in large US cites. *Transportation Research Part D: Transport and Environment* 18(1):39–45. https://doi.org/10.1016/j.trd.2012.09.007

[5] Egbue O, Long S (2012) Barriers to widespread adoption of electric vehicles: An analysis of consumer attitudes and perceptions. *Energy Policy* 48:717–729. https://doi.org/10.1016/J.ENPOL.2012.06.009

[6] Krupa JS, Rizzo DM, Eppstein MJ, Brad Lanute D, Gaalema DE, Lakkaraju K, Warrender CE (2014) Analysis of a consumer survey on plug-in hybrid electric vehicles. *Transportation Research Part A: Policy and Practice* 64:14–31. https://doi.org/10.1016/J.TRA.2014.02.019

[7] Lane B, Potter S (2007) The adoption of cleaner vehicles in the UK: exploring the consumer attitude–action gap. *Journal of Cleaner Production* 15(11–12):1085–1092. https://doi.org/10.1016/J.JCLEPRO.2006.05.026

[8] Peters A, Dütschke E (2014) How do Consumers Perceive Electric Vehicles? A Comparison of German Consumer Groups. *Journal of Environmental Policy & Planning* 16(3):359–377. https://doi.org/10.1080/1523908X.2013.879037

[9] Rezvani Z, Jansson J, Bodin J (2015) Advances in consumer electric vehicle adoption research: A review and research agenda. *Transportation Research Part D: Transport and Environment* 34:122–136. https://doi.org/10.1016/J.TRD.2014.10.010

[10] Gore C (2021) What drives battery electric vehicle adoption? Willingness to pay to reduce emissions through vehicle choice. Doctrol thesis (Ohio State University, Ohio).

[11] Carrel AL, White LV, Gore C, Shah H (2022) Subscribing to new technology: consumer preferences for short-term ownership of electric vehicles. *Transportation*. https://doi.org/10.1007/s11116-022-10353-1

[12] Ahmad F, Iqbal A, Ashraf I, Marzband M, others (2022) Optimal location of electric vehicle charging station and its impact on distribution network: A review. *Energy Reports* 8:2314–2333.

[13] Dua R, Hardman S, Bhatt Y, Suneja D (2021) Enablers and disablers to plug-in electric vehicle adoption in India: Insights from a survey of experts. *Energy Reports* 7:3171–3188.

[14] Hardman S, Tal G (2021) Understanding discontinuance among California's electric vehicle owners. *Nature Energy* 6(5):538–545.

[15] Franke T, Krems JF (2013) What drives range preferences in electric vehicle users? *Transport Policy* 30:56–62. https://doi.org/10.1016/J.TRANPOL.2013.07.005

[16] Yuan Q, Hao W, Su H, Bing G, Gui X, Safikhani A (2018) Investigation on Range Anxiety and Safety Buffer of Battery Electric Vehicle Drivers. *Journal of Advanced Transportation* 2018:1–11. https://doi.org/10.1155/2018/8301209

[17] Bubeck S, Tomaschek J, Fahl U (2016) Perspectives of electric mobility: Total cost of ownership of electric vehicles in Germany. *Transport Policy* 50:63–77. https://doi.org/10.1016/j.tranpol.2016.05.012

[18] Dumortier J, Siddiki S, Carley S, Cisney J, Krause RM, Lane BW, Rupp JA, Graham JD (2015) Effects of providing total cost of ownership information on consumers' intent to purchase a hybrid or plug-in electric vehicle. *Transportation Research Part A: Policy and Practice* 72:71–86. https://doi.org/10.1016/j.tra.2014.12.005

[19] Palmer K, Tate JE, Wadud Z, Nellthorp J (2018) Total cost of ownership and market share for hybrid and electric vehicles in the UK, US and Japan. *Applied Energy* 209:108–119. https://doi.org/10.1016/j.apenergy.2017.10.089

[20] Rusich A, Danielis R (2015) Total cost of ownership, social lifecycle cost and energy consumption of various automotive technologies in Italy. *Research in Transportation Economics* 50:3–16. https://doi.org/10.1016/j.retrec.2015.06.002

[21] Wu G, Inderbitzin A, Bening C (2015) Total cost of ownership of electric vehicles compared to conventional vehicles: A probabilistic analysis and projection across market segments. *Energy Policy* 80:196–214. https://doi.org/10.1016/j.enpol.2015.02.004

[22] Breetz HL, Salon D (2018) Do electric vehicles need subsidies? Ownership costs for conventional, hybrid, and electric vehicles in 14 U.S. cities. *Energy Policy* 120:238–249. https://doi.org/10.1016/j.enpol.2018.05.038

[23] Ko W, Hahn T-K (2013) Analysis of Consumer Preferences for Electric Vehicles. *IEEE Transactions on Smart Grid* 4(1):437–442. https://doi.org/10.1109/TSG.2012.2234770

[24] Helveston JP, Liu Y, Feit EM, Fuchs E, Klampfl E, Michalek JJ (2015) Will subsidies drive electric vehicle adoption? Measuring consumer preferences in the U.S. and China. *Transportation Research Part A: Policy and Practice* 73:96–112. https://doi.org/10.1016/j.tra.2015.01.002

[25] Hagman J, Ritzén S, Stier JJ, Susilo Y (2016) Total cost of ownership and its potential implications for battery electric vehicle diffusion. *Research in Transportation Business & Management* 18:11–17.

[26] Letmathe P, Suares M (2017) A consumer-oriented total cost of ownership model for different vehicle types in Germany. *Transportation Research Part D: Transport and Environment* 57:314–335.

[27] Vora AP, Jin X, Hoshing V, Saha T, Shaver G, Varigonda S, Wasynczuk O, Tyner WE (2017) Design-space exploration of series plug-in hybrid electric vehicles for medium-duty truck applications in a total cost-of-ownership framework. *Applied energy* 202:662–672.

[28] Christensen PA, Anderson PA, Harper GD, Lambert SM, Mrozik W, Rajaeifar MA, Wise MS, Heidrich O (2021) Risk management over the life cycle of lithium-ion batteries in electric vehicles. *Renewable and Sustainable Energy Reviews* 148:111240.

[29] Pedrosa G, Nobre H (2018) Second-hand electrical vehicles: A first look at the secondary market of modern EVs. *International Journal of Electric and Hybrid Vehicles* 10(3):236–252.

[30] Kwade A, Haselrieder W, Leithoff R, Modlinger A, Dietrich F, Droeder K (2018) Current status and challenges for automotive battery production technologies. *Nature Energy* 3(4):290–300.

[31] Bashash S, Moura SJ, Forman JC, Fathy HK (2011) Plug-in hybrid electric vehicle charge pattern optimization for energy cost and battery longevity. *Journal of power sources* 196(1):541–549.

[32] Neubauer J, Brooker A, Wood E (2012) Sensitivity of battery electric vehicle economics to drive patterns, vehicle range, and charge strategies. *Journal of Power Sources* 209:269–277.

[33] Yang F, Xie Y, Deng Y, Yuan C (2018) Predictive modeling of battery degradation and greenhouse gas emissions from US state-level electric vehicle operation. *Nature communications* 9(1):1–10.

[34] Martel F, Dube Y, Jaguemont J, Kelouwani S, Agbossou K (2017) Preemptive degradation-induced battery replacement for hybrid electric vehicles in sustained optimal extended-range driving conditions. *Journal of Energy Storage* 14:147–157.

[35] Neubauer JS, Wood E, Pesaran A (2015) A second life for electric vehicle batteries: answering questions on battery degradation and value. *SAE International Journal of Materials and Manufacturing* 8(2):544–553.

[36] Baars J, Domenech T, Bleischwitz R, Melin HE, Heidrich O (2021) Circular economy strategies for electric vehicle batteries reduce reliance on raw materials. *Nature Sustainability* 4(1):71–79.

[37] Skeete J-P, Wells P, Dong X, Heidrich O, Harper G (2020) Beyond the EVent horizon: Battery waste, recycling, and sustainability in the United Kingdom electric vehicle transition. *Energy Research & Social Science* 69:101581.

[38] Heymans C, Walker SB, Young SB, Fowler M (2014) Economic analysis of second use electric vehicle batteries for residential energy storage and load-levelling. *Energy Policy* 71:22–30.

[39] Jiao N, Evans S (2016) Business models for sustainability: the case of second-life electric vehicle batteries. *Procedia Cirp* 40:250–255.

[40] Dohmen T, Falk A, Huffman D, Sunde U, Schupp J, Wagner GG (2011) INDIVIDUAL RISK ATTITUDES: MEASUREMENT, DETERMINANTS, AND BEHAVIORAL CONSEQUENCES. *Journal of the European Economic Association* 9(3):522–550. https://doi.org/10.1111/j.1542-4774.2011.01015.x

[41] U.S. share of electric and hybrid vehicle sales increased in the second quarter of 2024 - U.S. Energy Information Administration (EIA) Available at https://www.eia.gov/todayinenergy/detail.php?id=62924