Case Study II: U.S. Electric Vehicle Market — PESTEL Analysis & Overview & Trends

Executive Summary

This report presents a comprehensive PESTEL-based analysis of the U.S. electric vehicle (EV) market, integrating advanced data analytics, hypothesis testing, and dashboard visualization. We leverage a national EV registration dataset to uncover operational risks and opportunities, especially in supply chain management and labor dynamics. Rigorous data cleaning (including AI-assisted MSRP value filling), hypothesis-driven analysis, and robust visualizations lead to actionable recommendations for policymakers and industry stakeholders.

1. Introduction & Selection Justification

The electric vehicle market in the United States is experiencing rapid transformation due to policy changes, technological breakthroughs, and evolving consumer preferences. This project was selected for its intersection with critical supply chain, environmental, and regulatory issues—making it ideal for PESTEL (Political, Economic, Social, Technological, Environmental, Legal) analysis. Our aim is to identify operational risks and strategic opportunities through data-driven insights.

2. Methodology

2.1 Data Collection

- **Source:**

  U.S. Department of Energy & Data.gov, "Electric Vehicle Population Data"

  https://catalog.data.gov/dataset/electric-vehicle-population-data

- **Scope:**

  239,000+ EV registrations, including make, model, type (BEV/PHEV), range, MSRP, geographic and demographic variables, from 2008–2025.

- **Relevance:**

  Data supports PESTEL analysis across technology adoption, economic trends, policy effects, and regional dynamics.

2.2 Data Cleaning and Preprocessing

1. Handling Missing Values (AI-Assisted MSRP Filling)

- **Major Challenge:**

  The Base MSRP column had over 50% of its values missing.

- **Strategy:**

  - For each missing MSRP, we checked for the same model in other rows. If multiple prices existed, we used the average.
  - If MSRP was unavailable in our dataset, we used ChatGPT to suggest plausible prices based on manufacturer websites (Tesla, Nissan, etc.), Edmunds, Car and Driver, and similar authoritative resources.
  - All external MSRP sources were documented (URLs/screenshots) and logged in an appendix.
  - If MSRP remained missing after these steps, the row was dropped for analysis integrity.

- **Tools:**

  Power BI DAX (ISBLANK, AVERAGEX), Python (Google Colab), ChatGPT for research and automation.

2. Null and Error Management in Other Columns

- Essential fields (Electric Range, Make, Model, Type) with unfillable nulls were removed.
- Non-essential fields with excessive nulls (e.g., Legislative District) were dropped.

3. Outlier Detection & Treatment

- Used the IQR method and visualized outliers via box plots.
- Obvious data errors (e.g., MSRP = 0, negative range) were dropped.
- Most statistical outliers were retained for transparency and shown in visualizations.

4. Duplicate and Data Type Checks

- Duplicates were removed using VINs.
- Converted relevant columns to proper numeric/categorical types and ensured naming consistency (BEV, PHEV).

5. Documentation and QA

- All changes are tracked in a data cleaning log.
- Summary statistics (record counts, missing values) recorded before and after cleaning.

2.3 Statistical Analysis & Hypothesis Testing

Hypothesis 1:

Battery Electric Vehicles (BEVs) have a significantly higher average electric range than Plug-in Hybrid Electric Vehicles (PHEVs).

- **Method:**
    - Box plot comparison, t-test
- **Result:**
    - BEVs' median and average ranges are much higher than PHEVs (t-statistic = 491.6, $p < 0.001$).
- **Interpretation:**
    - The difference is statistically significant and visually clear.

Hypothesis 2:

A higher MSRP is associated with a longer electric range (positive correlation).

- **Method:**
    - Scatter plot (MSRP vs. range), Pearson correlation
- **Result:**
    - No strong positive correlation found; higher price does **not** guarantee longer range.
- **Interpretation:**

- Some lower-priced models offer substantial range, showing that innovation is not limited to premium EVs.

2.4 Dashboard Visualization

- **Power BI Dashboard**:
  - KPI cards: Total EVs, Average MSRP, Market Share, Average Range
  - Bar/line charts: Top brands, year-over-year growth
  - Donut/pie: BEV vs. PHEV split
  - Box plot: BEV vs. PHEV range
  - Scatter plot: MSRP vs. range
  - Map: Regional EV adoption
  - Decomposition tree & Key Influencers: Factors driving PHEV adoption
  - Interactive filters (brand, year, county, etc.)

3. Results & Interpretation

3.1 Market Overview & Trends

- ~240,000 EV registrations (2025)
- 79% BEVs, 21% PHEVs
- Tesla commands ~42% market share; Model Y is the top model

- EV adoption accelerates post-2018, especially in urban/coastal counties
- Median BEV range: 170+ miles; PHEV median: 58 miles
- Average MSRP: ~$44,000 (after cleaning/filling)

3.2 Technology & Economic Insights

- **Hypothesis 1 Supported:**

  BEVs consistently outperform PHEVs in electric range (statistically significant).

- **Hypothesis 2 Not Supported:**

  Higher MSRP does not necessarily mean greater range; innovation occurs at multiple price points.

- **Brand/Model Diversity:**

  Affordable models (Nissan Leaf, Chevy Bolt) compete with premium brands on range.

3.3 Regional and Social Analysis

- Urban areas lead in EV adoption; rural/low-income regions lag behind
- Social equity gap highlights the need for targeted policy and infrastructure investment

3.4 Key Influencers & Risk

- Certain brands (Jeep, Toyota, Chrysler) are strong PHEV adopters; price and brand are key predictors
- Market is heavily concentrated in a few brands (risk/opportunity)
- PHEV adoption is linked to lower MSRP and specific brands

4. Environmental Impact Assessment (PESTEL Analysis)

Political

- Incentives and emissions policies are primary drivers of adoption and supply chain change.
- Risk: Regulatory shifts or uncertainty could slow market growth.

Economic

- High MSRP and supply chain constraints (chips, batteries) are key barriers.
- Opportunity: Falling battery costs, expanded incentives could accelerate adoption.

Social

- Widespread interest, but adoption is uneven (urban/rural, income gaps).
- Public perception and community charging access are crucial.

Technological

- Rapid BEV innovation in range and cost.
- Outlier models (e.g., Tesla Model S) lead in performance.
- Supply chain innovation (batteries, recycling) is critical.

Environmental

- Major emissions reductions, especially with renewable energy.
- Battery disposal/recycling and resource extraction are operational risks.

Legal

- Evolving standards for emissions, safety, and recycling.
- Compliance is a moving target as laws change.

5. Key Insights & Strategic Implications

- Technological leadership (high-range BEVs) is the core operational advantage.
- Market share concentration presents both supply risk and a benchmark for competitors.
- Policy stability and targeted economic incentives are vital for sustainable growth.
- Addressing the equity gap is necessary for market expansion and social acceptance.
- Supply chain and recycling innovation will determine long-term competitiveness.

6. Recommendations

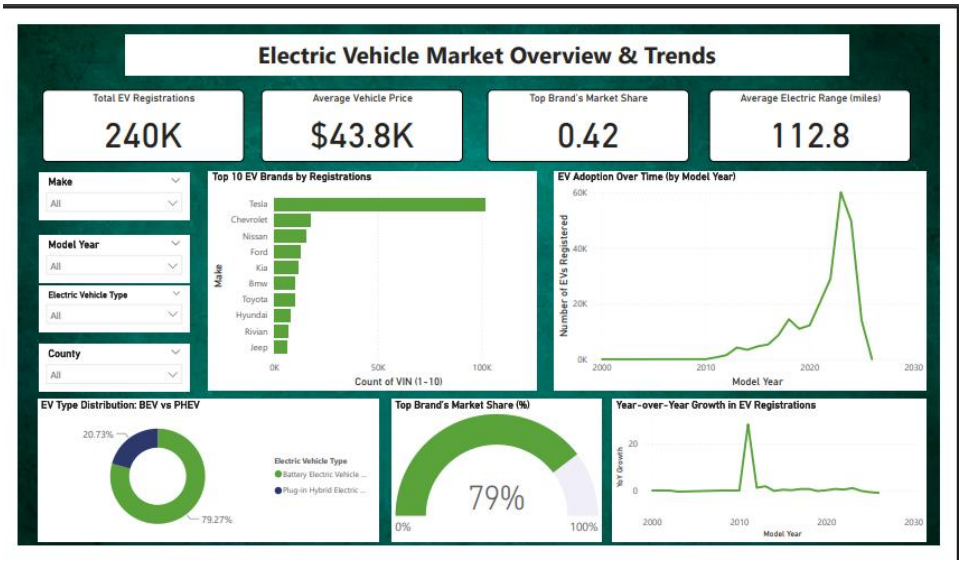
1. Expand incentives for affordable BEVs and rural charging.
2. Invest in supply chain resilience and battery recycling technology.
3. Accelerate infrastructure in underserved areas (community charging, service centers).
4. Encourage continuous innovation in range and battery technology.
5. Monitor and engage with policymakers on emissions, safety, and recycling standards.

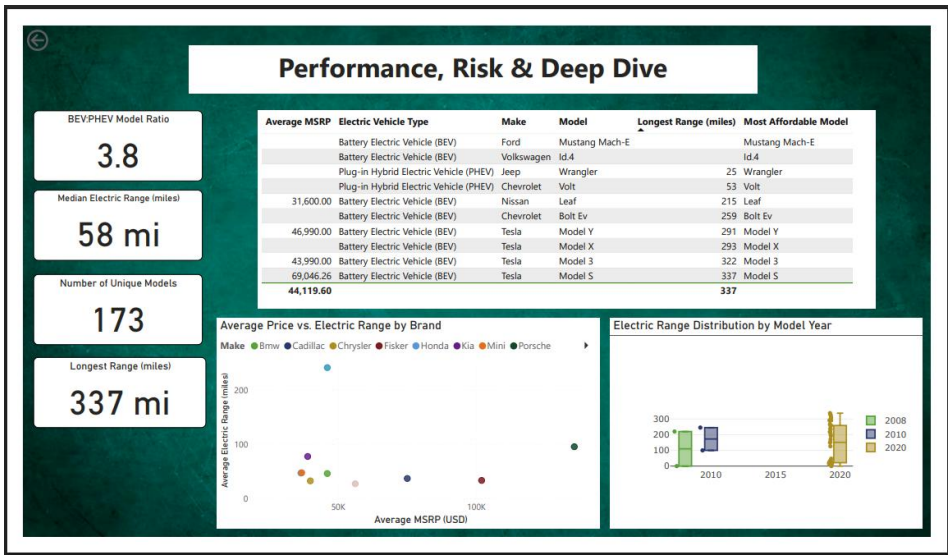
7. References

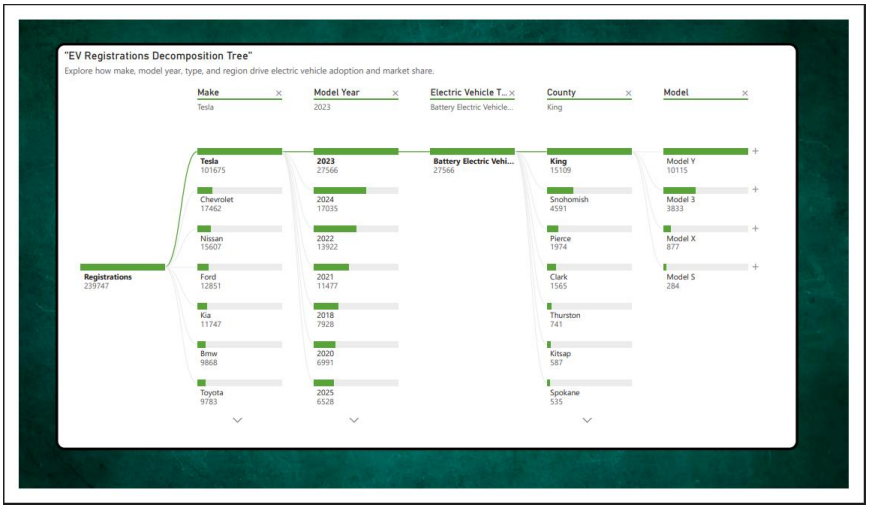
- U.S. Department of Energy. (2024). Electric Vehicle Population Data. Data.gov.
- Edmunds.com, CarandDriver.com, Manufacturer sites
- Power BI (2024), Microsoft
- Google Colab

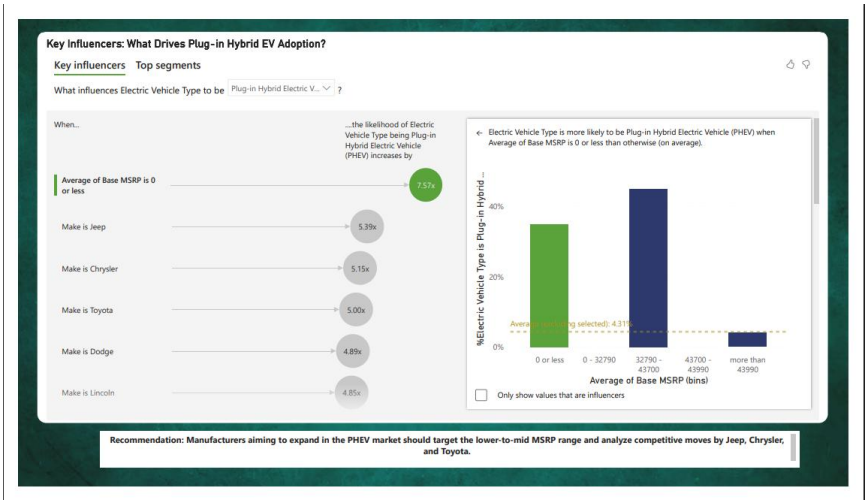
8. Appendices

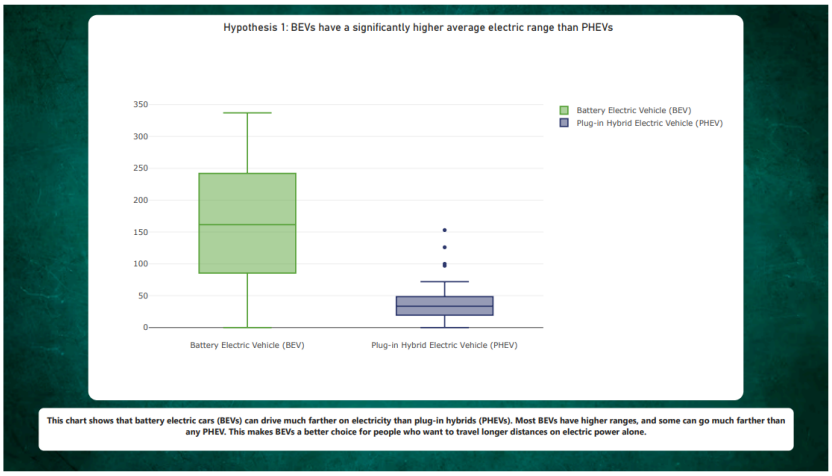
- **Appendix A:** Dashboard Screenshots

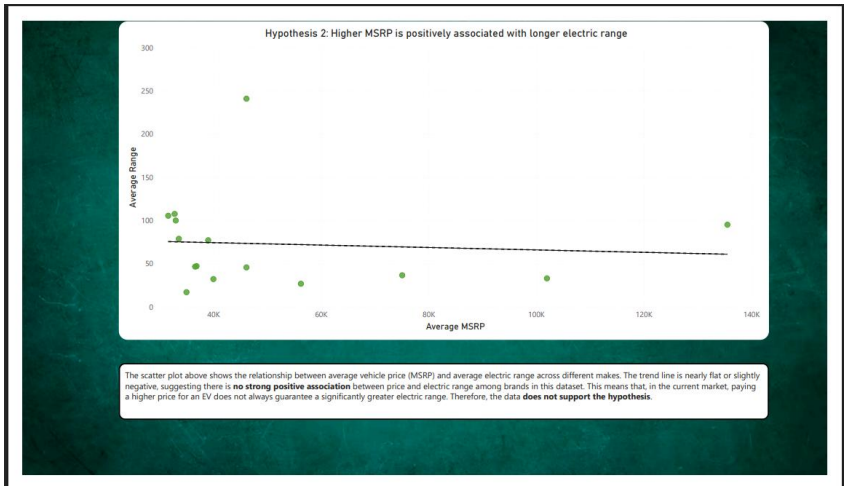



Performance, Risk & Deep Dive
BEV:PHEV Model Ratio
3.8
Median Electric Range (miles)
58 mi
Number of Unique Models
173
Longest Range (miles)
337 mi
Average MSRP | Electric Vehicle Type | Make | Model | Longest Range (miles) | Most Affordable Model
Battery Electric Vehicle (BEV) | Ford | Mustang Mach-E | Mustang Mach-E
Battery Electric Vehicle (BEV) | Volkswagen | Id.4 | Id.4
Plug-in Hybrid Electric Vehicle (PHEV) | Jeep | Wrangler | 25 | Wrangler
Plug-in Hybrid Electric Vehicle (PHEV) | Chevrolet | Volt | 53 | Volt
31,600.00 | Battery Electric Vehicle (BEV) | Nissan | Leaf | 215 | Leaf
Battery Electric Vehicle (BEV) | Chevrolet | Bolt Ev | 259 | Bolt Ev
46,990.00 | Battery Electric Vehicle (BEV) | Tesla | Model Y | 291 | Model Y
Battery Electric Vehicle (BEV) | Tesla | Model X | 293 | Model X
43,990.00 | Battery Electric Vehicle (BEV) | Tesla | Model 3 | 322 | Model 3
69,046.26 | Battery Electric Vehicle (BEV) | Tesla | Model S | 337 | Model S
44,119.60 | 337
Average Price vs. Electric Range by Brand
Make Bmw Cadillac Chrysler Fisker Honda Kia Mini Porsche
Average Electric Range (miles)
Average MSRP (USD)
Electric Range Distribution by Model Year
2008
2010
2020

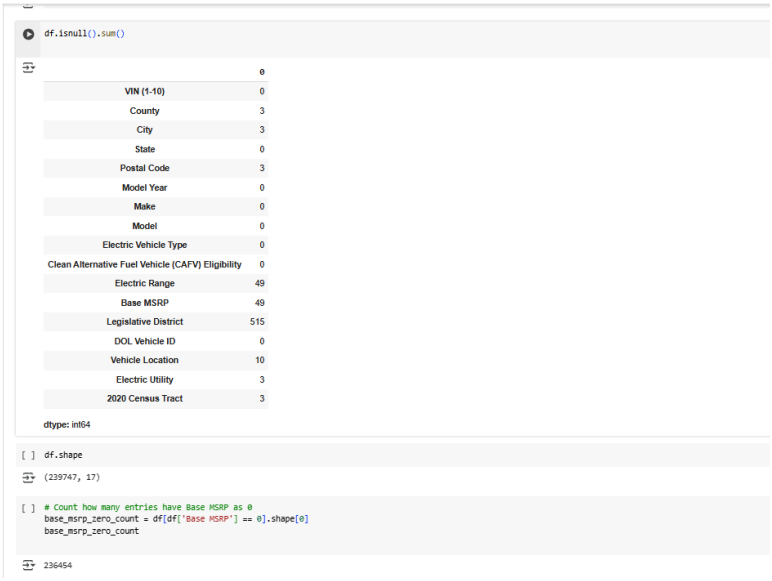

"EV Registrations Decomposition Tree"
Explore how make, model year, type, and region drive electric vehicle adoption and market share.
Make
Tesla
Model Year
2023
Electric Vehicle T...
Battery Electric Vehicle...
County
King
Model
Registrations
239747
Tesla
101675
Chevrolet
17462
Nissan
15607
Ford
12851
Kia
11747
Bmw
9868
Toyota
9783
2023
27566
2024
17035
2022
13922
2021
11477
2018
7928
2020
6991
2025
6528
Battery Electric Vehi...
27566
King
15109
Snohomish
4591
Pierce
1974
Clark
1565
Thurston
741
Kitsap
587
Spokane
535
Model Y
10115
Model 3
3833
Model X
877
Model S
284


Key Influencers: What Drives Plug-in Hybrid EV Adoption?
Key influencers
Top segments
What influences Electric Vehicle Type to be
Plug-in Hybrid Electric V...
?
When...
...the likelihood of Electric Vehicle Type being Plug-in Hybrid Electric Vehicle (PHEV) increases by
Average of Base MSRP is 0 or less
7.57x
Make is Jeep
5.39x
Make is Chrysler
5.15x
Make is Toyota
5.00x
Make is Dodge
4.89x
Make is Lincoln
4.85x
Electric Vehicle Type is more likely to be Plug-in Hybrid Electric Vehicle (PHEV) when Average of Base MSRP is 0 or less than otherwise (on average).
%Electric Vehicle Type is Plug-in Hybrid ...
40%
20%
0%
0 or less
0 - 32790
32790 - 43700
43700 - 43990
more than 43990
Average of Base MSRP (bins)
Only show values that are influencers
Recommendation: Manufacturers aiming to expand in the PHEV market should target the lower-to-mid MSRP range and analyze competitive moves by Jeep, Chrysler, and Toyota.





- **Appendix B:** Data Cleaning Log & Python/DAX Code



```
df.isnull().sum()
```

	0
VIN (1-10)	0
County	3
City	3
State	0
Postal Code	3
Model Year	0
Make	0
Model	0
Electric Vehicle Type	0
Clean Alternative Fuel Vehicle (CAFV) Eligibility	0
Electric Range	49
Base MSRP	49
Legislative District	515
DOL Vehicle ID	0
Vehicle Location	10
Electric Utility	3
2020 Census Tract	3

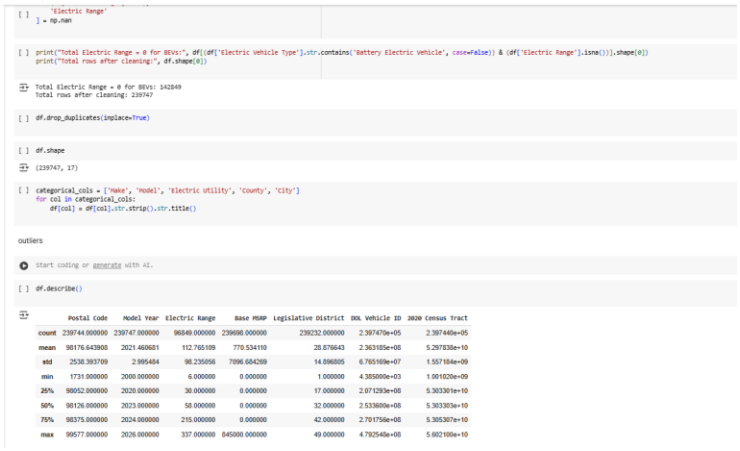
dtype: int64

```
df.shape
```

```
(239747, 17)
```

```
# Count how many entries have Base MSRP as 0
base_msrp_zero_count = df[df['Base MSRP'] == 0].shape[0]
base_msrp_zero_count
```

```
236454
```



```
    'Electric Range'
] = np.nan
```

```
print("Total Electric Range = 0 for BEVs:", df[(df['Electric Vehicle Type'].str.contains('Battery Electric Vehicle', case=False)) & (df['Electric Range'].isna())].shape[0])
print("Total rows after cleaning:", df.shape[0])
```

```
Total Electric Range = 0 for BEVs: 142849
Total rows after cleaning: 239747
```

```
df.drop_duplicates(inplace=True)
```

```
df.shape
```

```
(239747, 17)
```

```
categorical_cols = ['Make', 'Model', 'Electric Utility', 'County', 'City']
for col in categorical_cols:
    df[col] = df[col].str.strip().str.title()
```

outliers

```
Start coding or generate with AI.
```

```
df.describe()
```

	Postal Code	Model Year	Electric Range	Base MSRP	Legislative District	DOL Vehicle ID	2020 Census Tract
count	239744.000000	239747.000000	96849.000000	239698.000000	239232.000000	2.397470e+05	2.397440e+05
mean	98176.643908	2021.460681	112.765109	770.534110	28.876643	2.363185e+08	5.297838e+10
std	2538.393709	2.995484	98.235056	7096.684269	14.896805	6.765169e+07	1.557184e+09
min	1731.000000	2000.000000	6.000000	0.000000	1.000000	4.385000e+03	1.001020e+09
25%	98052.000000	2020.000000	30.000000	0.000000	17.000000	2.071293e+08	5.303301e+10
50%	98126.000000	2023.000000	58.000000	0.000000	32.000000	2.533600e+08	5.303303e+10
75%	98375.000000	2024.000000	215.000000	0.000000	42.000000	2.701756e+08	5.305307e+10
max	99577.000000	2026.000000	337.000000	845000.000000	49.000000	4.792548e+08	5.602100e+10

visvual

```
msrp_fill = pd.DataFrame({
    'Model': ['Model 3','Model Y','Leaf','Bolt EV','Niro','Soul Ev','I3','Ioniq','Kona','E-Golf','Clarity'],
    'filled_msrp': [43990, 46990, 31600, 36500, 39990, 33950, 44450, 33245, 34000, 32790, 36600]
})

# Merge and fill
df = df.merge(msrp_fill, on='Model', how='left')
df['Base MSRP'] = df['Base MSRP'].fillna(df['filled_msrp'])
df.drop(columns='filled_msrp', inplace=True)

# Check remaining missing MSRP
print("Remaining missing MSRP rows:", df['Base MSRP'].isna().sum())
```

```
df.to_csv('cleaned_data.csv', index=False)
```

```
from google.colab import files
files.download('cleaned_data.csv')
```

- **Appendix C:** MSRP Fill Documentation (with URLs/source screenshots)

Model	Filled MSRP (USD)	Source Description
Model 3	43,990	tesla.com base price
Model Y	46,990	tesla.com base price
Leaf	31,600	nissanusa.com / KBB
Bolt EV	36,500	chevrolet.com base MSRP
Niro	39,990	kia.com Niro EV MSRP
Soul Ev	33,950	kia.com base MSRP
I3	44,450	bmwusa.com / Edmunds
Ioniq	33,245	hyundaiusa.com
Kona	34,000	hyundaiusa.com Kona EV base price
E-Golf	32,790	vw.com e-Golf MSRP
Clarity	36,600	honda.com (Clarity Electric base MSRP)