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Wireless Charging Revenue Generation from Kansas Pavements

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Kansas State University Transportation Center

Kansas
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16 **Abstract**

In addition to the expected environmental and energy security related benefits, however, high EV adoption raises concerns about the negative impact on revenue generation that has previously come from the gasoline tax. The Highway Trust Fund (HTF) has been challenged repeatedly for future sustenance, including declining gas tax revenue as consumers choose plug-in EVs (PEVs). Similar to other states, road maintenance and improvements in Kansas are dependent upon the availability and distribution of state highway funds. Therefore, the identification of alternative revenue sources, such as wireless charging pavements, is vital to maintain a sustainable flow of highway funds as EV usage increases in Kansas.

Wireless charging pavements, which leverage induction charging via primary and secondary coils in concrete pavements, allow an EV to charge either while stationary or traveling as fast as 62 miles per hour (mph) (e.g., the Qualcomm developed testbed). Wireless charging pavements can help reduce the “range anxiety” of EV owners and eventually increase the EV market share in the geographic region where wireless charging pavements are used. A properly designed network of wireless charging pavements that utilizes induction charging coils only on selected road segments would allow the Kansas Department of Transportation (KDOT) and/or the Kansas Turnpike Authority (KTA) to charge EV owners fees for wireless charging, thereby generating sustainable revenue.

Before investing in this potential revenue-generating technology, however, financial and economic feasibility must be assessed, the EV market in Kansas must be better understood, and the response to the introduction of wireless charging pavements must be estimated. Therefore, this study utilized five main tasks to accomplish the research objectives. Task 1 synthesized current wireless charging technologies, while Task 2 estimated existing and projected EV ownership and usage trends for Kansas. Task 3 developed the EV market share model, and Task 4 investigated the correlation between charging station availability and PEV adoption, including assessment of the effects of charging station availability, gasoline prices, and home charging installation costs on PEV market adoption. Task 5 explored and summarized pricing/business/cost-benefit models for EV charging from pavements.

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Final Report

Prepared by

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A Report on Research Sponsored by

THE KANSAS DEPARTMENT OF TRANSPORTATION
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January 2025

PREFACE

The Kansas Department of Transportation's (KDOT) Kansas Transportation Research and New-Developments (K-TRAN) Research Program funded this research project. It is an ongoing, cooperative and comprehensive research program addressing transportation needs of the state of Kansas utilizing academic and research resources from KDOT, Kansas State University and the University of Kansas. Transportation professionals in KDOT and the universities jointly develop the projects included in the research program.

NOTICE

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Abstract

The electrification of transportation systems—roads and vehicles—has increased in popularity in the last decade due to federal and targeted incentives to encourage increased usage of electric vehicles (EVs). As a result, the need for an accessible, affordable, and sustainable charging infrastructure has emerged. Consequently, the current U.S. presidential administration supports the building of a novel national network of charging stations (approximately 500,000 access points) throughout the United States. The National Electric Vehicle Infrastructure (NEVI) program is expected to offer states $5 billion in formula funding to build charging infrastructure along highway corridors to increase charging access in rural and disadvantaged communities.

In addition to the expected environmental and energy security related benefits, however, high EV adoption raises concerns about the negative impact on revenue generation that has previously come from the gasoline tax. The Highway Trust Fund (HTF) has been challenged repeatedly for future sustenance, including declining gas tax revenue as consumers choose plug-in EVs (PEVs). Similar to other states, road maintenance and improvements in Kansas are dependent upon the availability and distribution of state highway funds. Therefore, the identification of alternative revenue sources, such as wireless charging pavements, is vital to maintain a sustainable flow of highway funds as EV usage increases in Kansas.

Wireless charging pavements, which leverage induction charging via primary and secondary coils in concrete pavements, allow an EV to charge either while stationary or traveling as fast as 62 miles per hour (mph) (e.g., the *Qualcomm* developed testbed). Wireless charging pavements can help reduce the "range anxiety" of EV owners and eventually increase the EV market share in the geographic region where wireless charging pavements are used. A properly designed network of wireless charging pavements that utilizes induction charging coils only on selected road segments would allow the Kansas Department of Transportation (KDOT) and/or the Kansas Turnpike Authority (KTA) to charge EV owners fees for wireless charging, thereby generating sustainable revenue.

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the response to the introduction of wireless charging pavements must be estimated. Therefore, this study utilized five main tasks to accomplish the research objectives. **Task 1** synthesized current wireless charging technologies, while **Task 2** estimated existing and projected EV ownership and usage trends for Kansas. **Task 3** developed the EV market share model, and **Task 4** investigated the correlation between charging station availability and PEV adoption, including assessment of the effects of charging station availability, gasoline prices, and home charging installation costs on PEV market adoption. **Task 5** explored and summarized pricing/business/cost-benefit models for EV charging from pavements.

We have used the EV/PEV sales data from Kansas to analyze current EV adoption trends and applied MA3T, the EV market share prediction tool developed by the Oak Ridge National Laboratory (U.S. Department of Energy), to assess the sensitivity of market share as a function of charging infrastructure improvement, changes in gasoline prices, and the deployment of dynamic wireless power transfer (DWPT) or dynamic wireless charging (DWC) on Kansas roads. Research results summarized the financial aspects of DWPT installation from the existing literature (theoretical models and prototypes from countries around the world).

Acknowledgments

We thank the Kansas Department of Transportation for supporting this research. We are grateful for the guidance from our project monitor Mike Floberg. Also, we would like to acknowledge the guidance from Dr. Zhenhong Lin from the Oak Ridge National Laboratory, who helped us to understand the MA3T market simulation tool and develop the scenarios.

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Chapter 1: Review of EV Charging Technologies and Current EV Adoption Trends in Kansas

This section summarizes the outcome of **Task 1** and **Task 2**. The primary research objective was to review existing electric vehicle (EV) charging technologies, including dynamic wireless power transfer (DWPT) and EV adoption trends in Kansas. We have also reviewed and compiled the current literature on EV charging technologies, including a review of powertrain technologies (i.e., wireless vs. wired charging, stationary vs. dynamic charging), the existing cost structure (i.e., how much a U.S. customer pays to charge an EV from a non-home charging station), and an overview of charging station distribution data across the U.S. and in Kansas.

1.1 Electric Vehicle Technology Types

The Alternative Fuels Data Center (AFDC), managed by the U.S. Department of Energy (DOE), details how various fuel types can power vehicles. This research focused on two classes of plug-in electric vehicles (PEVs) when considering the EV charging infrastructure:

(I) All-Electric Vehicles (Battery Electric Vehicles or BEVs): BEVs are powered by battery packs that can be charged by electrical sources (either grid or off-board resources). BEVs are considered as zero-emission vehicles by the US Environmental Protection Agency (EPA) because BEVs do not produce any direct tailpipe emissions.

(II) Plug-in Hybrid Electric Vehicles (PHEVs): PHEVs are equipped with both electric motors and internal combustion engines (ICE). The electric motors are powered by battery packs which can be charged through charging equipment and regenerative braking (unlike BEVs). PHEVs can have either parallel (mechanical coupling of both electric motor and the ICE engine with wheels) and serial (electric motors drive the wheels most of the time, and the ICE engine helps to generate the electricity—sometimes known as the extended electric vehicles. The ICE engine can drive the vehicles at a low/depleted battery state).

The Hybrid Electric Vehicles (HEVs) mostly use liquid fuels (e.g., gasoline, diesel) and small batteries installed inside the vehicle can be charged by regenerative braking. HEVs have both internal combustion engines and small electric motors. Unlike the PEVs, HEVs cannot be plugged in to off-board electricity sources to charge the battery. HEVs recapture the energy generally lost during braking (the electric motor acts as a generator and stores the energy in the battery). Henceforth, we refer to only PEV when we mention EV throughout the report.

1.2 Current State of PEV Adoption

To highlight the current state of PEV adoption in the United States: Figure 1.1 illustrates the alternative vehicle market share based on 2020 U.S. vehicle registration data, Figure 1.2 shows PEV sales (by model) from 2011 to 2019, and Figure 1.3 displays available light-duty alternative fuel vehicle (AFV), diesel, and HEV models to purchase by year.

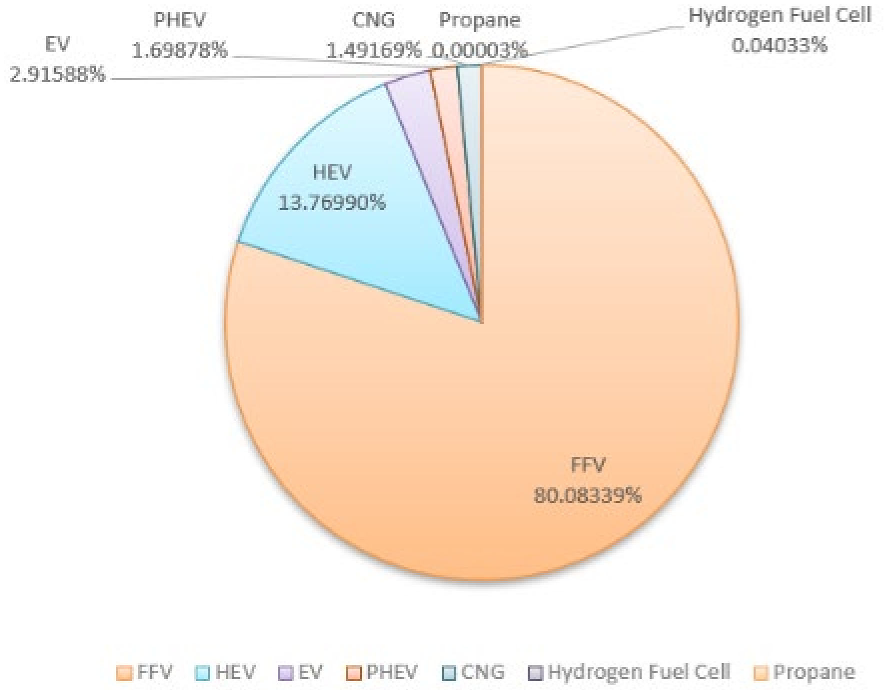
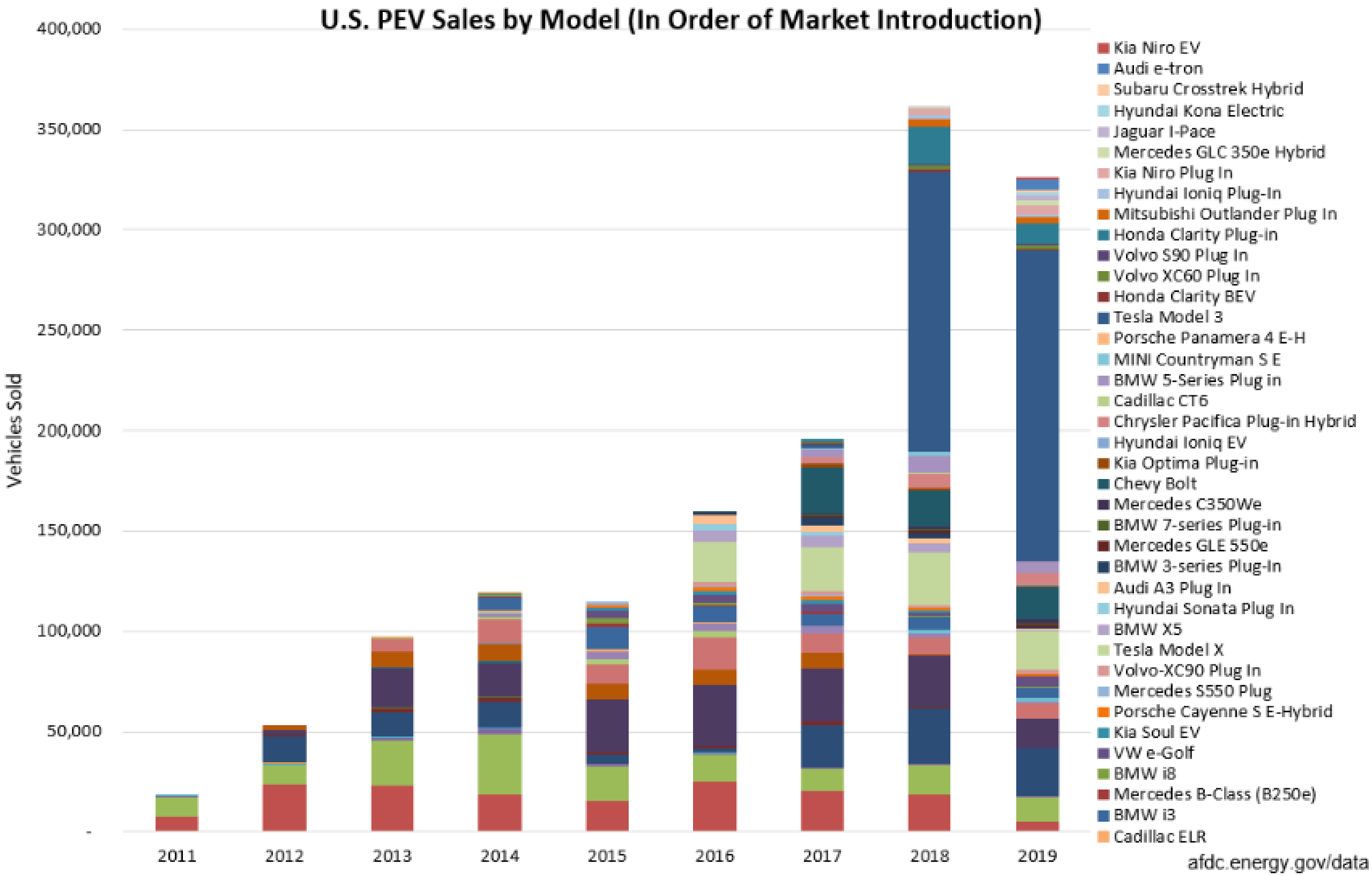


Figure 1.1: Alternative Vehicle Market Share in the United States
Source: afdc.energy.gov/data



afdc.energy.gov/data

Figure 1.2: PEV Sales in the United States by Model (2011–2019)

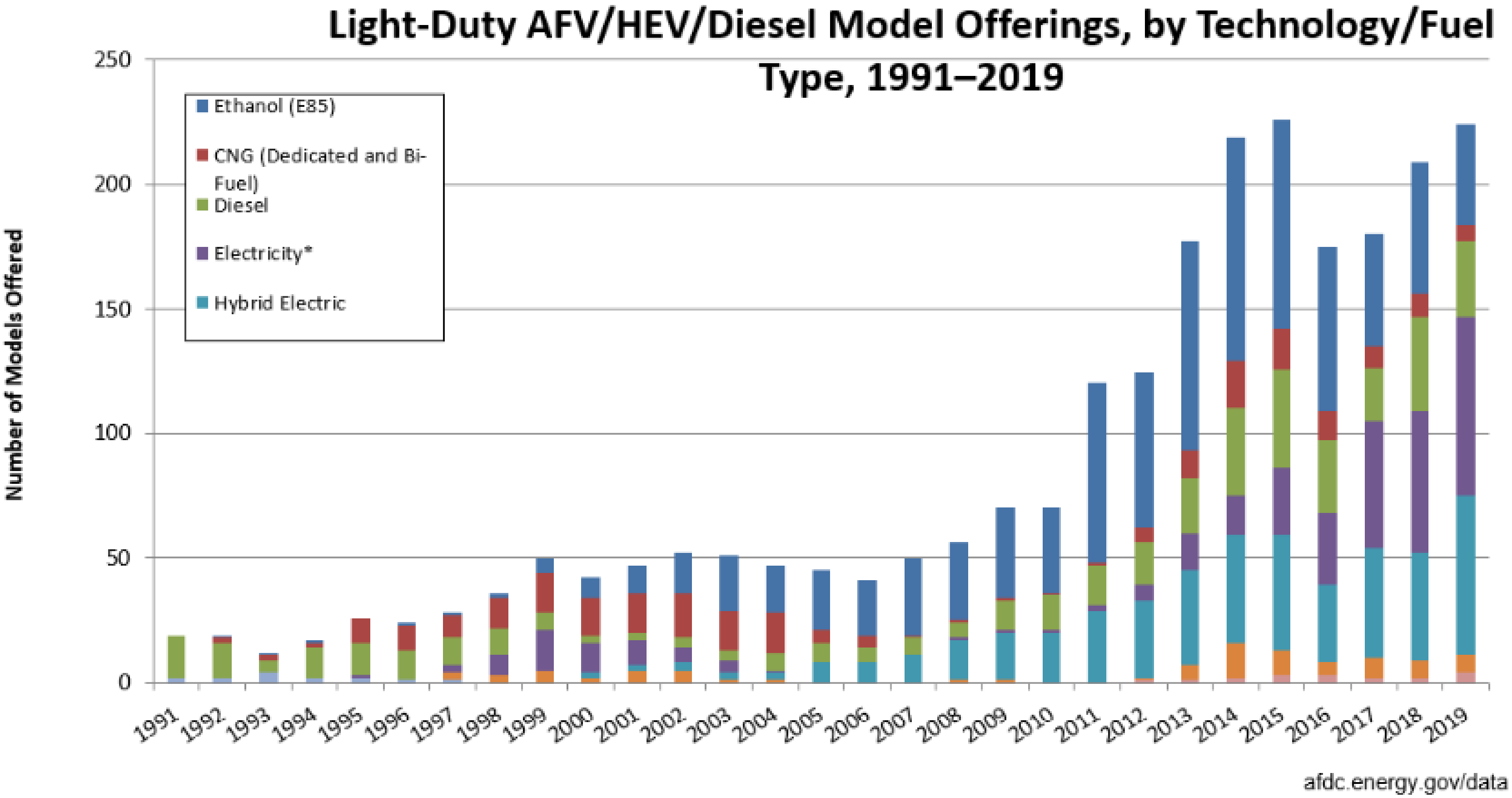


Figure 1.3: Vehicle Model Offerings by Technology/Fuel in the United States (1991 – 2019)

1.3 Overview of PEV Charging Infrastructure

Historically, most PEVs charge at consumers’ residences or at fleet facilities. However, workplace charging stations and charging stations at public destinations have become increasingly popular. The need for a comprehensive charging infrastructure is a critical catalyst to reach the critical mass of EVs nationwide. The following subsections describe standard technical terms associated with PEV charging and charging options for consumers in the United States.

1.3.1 Charging Station/Location Components

The AFDC (n.d.) and charging infrastructure industry apply the Open Charge Point Interface (OCPI) protocol to describe three primary elements for every charging station: the location, the electric vehicle supply equipment (EVSE) port, and the connector. The station location refers to the physical location (e.g., garage in a home, parking lot at a grocery store) with EVSE port(s) and connectors. A charging post usually contains various connector types on one EVSE port, but only one vehicle can be charged at a time. The connectors (or plugs) are plugged directly into the vehicles to charge.

1.3.2 Charging Equipment

Charging time for a PEV ranges from 20 minutes to 20 hours depending on the charging equipment used, battery type and capacity, and state of charge before charging. Charging assets are generally classified by the rate at which batteries are charged. As shown in Table 1.1, three common charging interfaces in commercial settings are Level-1 AC, Level-2 AC, and DC Fast Charger.

Table 1.1: Descriptions of Charging Point Interfaces

Charging Type	Where can we find one?	Market Share	Voltage	Rate of Charging
Level-1 AC	Common Households (120 V outlets)	~5%	120 V	2–5 miles of range per one hour of charging
Level-2 AC	Mostly commercial and industrial locations. Homeowners can install Level-2 AC charging. This is the most common charging option in public charging stations and workplaces.	~80%	240 V (residential) or 208 V (commercial)	10–20 miles of range per one hour of charging
DC Fast Charger	Public charging stations—limited availability	~15%	208/480 V AC three-phase input	60–80 miles of range per 20 minutes of charging

1.4 Additional Charging Options

Faster AC charging: The SAE J3068 (SAE, 2022) describes fast AC charging using three-phase voltage, typically 208/120 V and 480/277 V, with power levels ranging from 6 to 120 kW. Another charging option, the Extreme Fast Charging (XFC), can output power as high as 350 kW. Consequently, manufacturers are expanding the XFC network in the United States. According to the AFDC, most existing models of PEVs cannot be charged at rates higher than 50 kW. However, vehicle technology is advancing, and the new PEV models are expected to fully utilize the XFC networks.

Chapter 2: Inductive Charging via Wireless Power Transfer

Instead of a direct plug-in to an electric power source, PEVs can also be charged via inductive charging equipment that leverages electromagnetic fields to transfer power. Wireless power transfer (WPT), or wireless charging, is central to inductive charging. Some commercially available wireless charging stations operate similarly to Level 2 charging equipment.

WPT technology can be deployed in three standard forms: as stationary wireless charging, dynamic (in-motion) wireless charging, and quasi-dynamic charging. In stationary wireless charging, PEVs can be charged at parking spaces (e.g., public charging or employer-provided parking) and inside residential garages without being plugged into an electrical power source. For dynamic wireless charging, PEVs can be charged while moving using infrastructure installed underneath road (pavement) surfaces. The Oak Ridge National Laboratory (ORNL) has recently developed dynamic charging supports for heavy-duty trucks moving on highways (ORNL, 2021). Dynamic wireless charging is also a form of electrified roadway (ER) systems that enable roads to serve as charging infrastructure for PEVs, including overhead conductive systems and conductive rail systems. However, ER systems are not a mature technology, and many aspects must still be explored and understood prior to large-scale deployment. Finally, a quasi-dynamic charging system allows charging only when PEVs accelerate and decelerate.

The scope of this study was limited to WPT-based PEV charging technology that utilizes either electromagnetic induction or magnetic resonance with charging equipment installed below road surfaces.

2.1 Distribution of Charging Stations in the US

According to AFDC data, the United States had 57,707 active charging stations in December 2021, with concentrated densities along the East and West Coasts (Figure 2.1). As shown in the figure, the eastern portion of the United States has a denser spatial distribution than the western states. In contrast, the central states had less charging infrastructure as of January 2021. The AFDC data also reveal 537 unique pricing structures for the charging stations (Table 2.1).

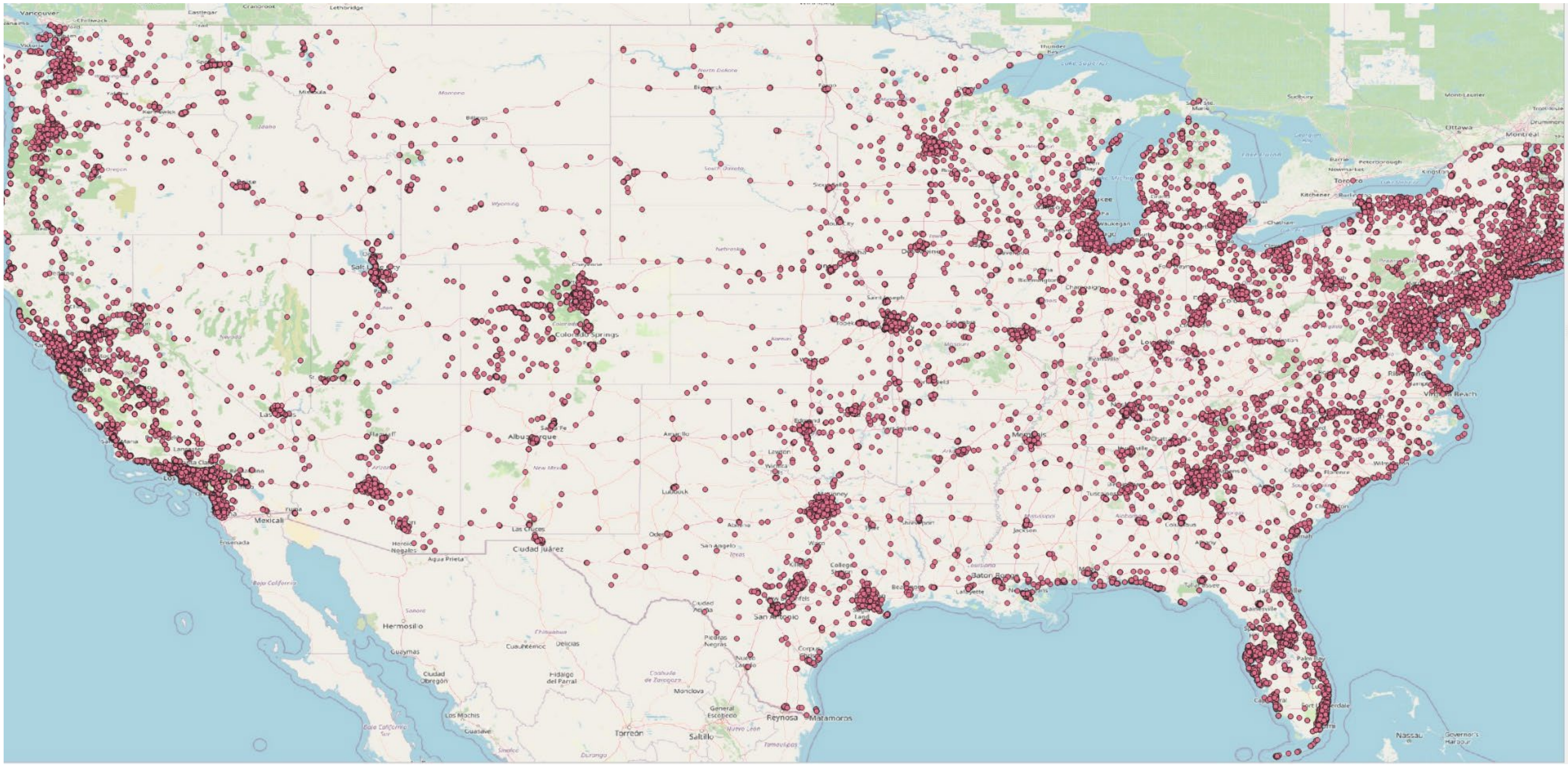


Figure 2.1: Available PEV Charging Stations

Source: AFDC (n.d.)

Table 2.1: Charging Station Pricing in the United States

No.	***How do customers Pay for EV Charging?***
1	Free
2	Pay to park
3	Free; parking fee
4	$12 parking fee
5	$7 per session
6	Free; parking is $8 per day
7	$1 per hour for first two hours; $3 per hour thereafter
8	$9 parking fee
9	Pay for garage; charging is free
10	$1.50/hr
11	$2 parking fee
12	$0.75 per hour parking fee
13	$1 per first and second half-hour parking fee; $1 per each additional hour parking fee
14	Free; metered parking
15	Free; meter charge
16	$10 per session
17	Free for guests; $10 for non-guests
18	$3 per session
19	$6 per session
20	$1 per hour
21	$0.25 per hour parking fee
22	$1.50 per hour
23	Variable fee
24	$0.13 per kWh

No.	How do customers Pay for EV Charging?
25	$1 per hour parking fee; maximum session time of 2 hours
26	$2 per hour
27	$6 per charge
28	Free; 3-hour parking limit
29	Free; requires GreenLots app
30	Variable parking fee
31	$2 per session
32	Fee required
33	$2 for first hour; $1 per each hour thereafter
34	$1 per half hour parking fee; maximum payment of $16
35	$1 per half hour parking fee; maximum payment of $16
36	$2.00 per hour
37	$15 per session
38	$3 for first hour; then $5 per hour
39	Free; pay to park
40	$2 per hour; maximum session time of 4 hours
41	$7 for EV and parking permit
42	$5 parking fee
43	Free chargers - garage parking rates
44	EV pay to park
45	Free for customers
46	$1.20 per hour; $0.35 transaction fee
47	$5 per hour for non-customers
48	$7 per day; free for vehicles with EV license plates
49	Pay to park; free to charge
50	$7 per session; free with EV license plate

No.	How do customers Pay for EV Charging?
51	$7 per session; free with EV license plate
52	$5 per session for non-guests
53	Free; $21 per day parking fee
54	$2 per hour parking fee
55	Free for first 2 hours; $5 per hour thereafter
56	Free for first 1 hour; $5 per hour thereafter
57	$1 per hour; maximum payment of $3
58	$3 per session for ticket holders; $1 per hour parking fee
59	$1.25 per 20 minutes
60	$1.50 for 1 hour; $2.50 for 2 hours; $5.00 for 4 hours
61	$0.75 per hour
62	$0.25 per hour
63	$20 per session for non-guests
64	$0.50 per hour
65	$5 per session
66	$12 per session
67	$0.23 per kWh
68	Free; need key card from desk
69	$0.35 per kWh
70	$5 per hour
71	$1 per hour; 3-hour maximum
72	Maximum payment of $15 for customers; maximum payment of $29.95 for non-customers
73	$5 per 4-hour session
74	Free for guests
75	Level 2: $4 per session or $19.99 for monthly plan

No.	How do customers Pay for EV Charging?
76	Level 2: $4 per session or $19.99 for monthly plan; DC Fast: $7.50 per session or $19.99 for monthly plan
77	DC Fast: $7.50 per session or $19.99 for monthly plan; Level 2: $4 per session or $19.99 for monthly plan
78	$0.20 per kWh
79	$3 per hour
80	$0.99 per hour
81	$2 per hour for first two hours; $4 per hour thereafter
82	$2 per hour for first 2 hours; $3 per hour each additional hour
83	Free; maximum session time of 2 hours
84	$1 per hour for first 2 hours; $5 per hour thereafter
85	Free for 30 minutes; $10 after first 30 minutes
86	$5 for 2 hours
87	$0.50 per kWh
88	$25 parking fee for non-guests
89	Free; pay garage
90	Free for clients; $1.50 per hour for non-clients
91	Free until September 2021
92	$15 per month for JUMPSMART volunteers; $30 per month for non-volunteers
93	$1.50 per session plus an additional $0.10 per minute
94	Free; $3 per hour to park
95	Free to charge; pay to park
96	$10 parking fee
97	$8 parking fee in garage
98	$1 per 4-hours for first four hours; $10 per hour thereafter
99	$0.10 per kWh
100	Level 2: $1 per hour; DC Fast: $5 per hour

No.	How do customers Pay for EV Charging?
101	Free; pay for parking
102	$2.00 per session; first 5 minutes free; minimum payment of $0.50
103	$0.25 per kWh
104	DC Fast: $7.50 per session or $19.99 for monthly plan
105	Free for first 3 hours; $3.00 per hour thereafter
106	$2–$4 per hour
107	$0.30 per kWh
108	$0.50 per hour; $0.30 per kWh
109	$.50/KWh for first 4 hours; $1.50 per hour after the first 4 hours; $10 maximum per session
110	$0.50/kWh first 4 hours; $1.50/hour after 4 hours; Maximum charging fee: $10.00
111	$0.50 per hour parking fee
112	$0.59 per kWh
113	$1.50 per hour for general public; $1 per hour for NAU faculty, staff, and students
114	$1.50 per hour for general public; $1 per hour for NAU faculty, staff, and students
115	Drivers must make minimum $75 membership donation annually to SACE to have access to charger
116	$1 per hour 5:30 p.m.–7:00 a.m.
117	Parking fee
118	Minimum payment of $5; maximum payment of $15; maximum session time of 1 hour
119	$1 per hour; free for customers
120	Free to charge; $3 per hour for parking
121	$5 per hour until 5:00 p.m.; free after 5:00 p.m.
122	Free; 4-hour limit

No.	How do customers Pay for EV Charging?
123	Free for monthly parkers
124	$1.25 per hour
125	DC fast: $0.23 per kWh
126	$2 per 30 minutes
127	$2.20 per hour
128	Free with parking fee
129	Free; charge for maximum of 4 hours
130	L1: $0.89 per kWh; L2: $1.40 per kWh
131	$23 early bird (before 9:00 a.m.); $30 after, regardless of charging time; pay at garage office.
132	Free during weekday; $6.00 holidays and weekends
133	Free; donations encouraged
134	$0.25 per minute; $0.20 per minute for NASA employees
135	$1.50 per hour; need Liberty Hydra App to obtain access code
136	Level 2: Free; DC Fast: $0.08 per minute for first 30 minutes, $0.20 per minute thereafter
137	$0.30 per kWh for first three hours; $10 fee thereafter
138	$0.15 per kWh
139	$50 refundable deposit per session
140	Payment through SemaConnect
141	$0.11 per kWh
142	$15 per month
143	$3 per month
144	$0.32 per kWh
145	$25 per hour
146	$5 per 4-hour session for non-guests
147	$0.18 per kWh

No.	***How do customers Pay for EV Charging?***
148	Level 2: $0.59 per kWh
149	Level 2: $0.49 per kWh
150	Level 2: $0.24 per kWh
151	Level 2: $0.03 per minute
152	Level 2: $0.03 per 30 seconds
153	Level 2: $0.69 per kWh
154	Level 2: $0.29 per kWh
155	Level 2: $0.18 per kWh
156	Level 2: $0.55 per kWh
157	Level 2: $0.1 per kWh
158	Level 2: $0.3 per kWh
159	Level 2: $1.5 per hour
160	Level 2: $0.41 per kWh
161	Level 2: $0.39 per kWh
162	Level 2: $9.99 per session
163	Level 2: $0.2 per kWh
164	Pricing is based on PG&E rate; minimum $0.20 per kWh, maximum $0.56 per kWh
165	Level 2: $0.35 per kWh
166	$4 per hour
167	$1.35 per hour for first 4 hours; $3.00 per hour thereafter
168	$1 initiation fee + $0.32 per minute
169	Free; must pay park entrance fee
170	$0.28 per kWh; $0.26 per minute above 60 kW and $0.13 per minute at or below 60 kW
171	Donations accepted
172	$0.18 per kWh for 20 minutes; $20 per hour after; parking fee

No.	How do customers Pay for EV Charging?
173	$0.10 per kWh; parking fee
174	$0.10 per kWh; pay parking
175	$20 per session for non-guests
176	$0.24 per minute
177	$0.29 per kWh
178	Level 2: $0.04 per minute
179	Level 2: free; DC fast: fee required
180	$2 per hour for first hour; $20 per hour thereafter
181	$1 per hour for first 4 hours; $3 per hour thereafter
182	$2.50 per hour
183	Free until September
184	$15 per session for non-guests
185	$0.27 per kw
186	Free to faculty with pass; $5 for visitors
187	By kWh
188	$4 per session
189	$0.42 per kWh
190	$1 per hour; 4-hour limit
191	$1 per kWh
192	Valet fee overnight
193	Free for guests; $5 per charge for public
194	Level 2: $0.26 per kWh
195	$.30 per kWh
196	Pricing varies by kWh
197	$4.17 per month through Austin Energy's Plug-In EVerywhere℠ program
198	$0.49 per kWh from 6:00 a.m.–9:00 a.m.; 4:00 p.m. –7:00 p.m.; $0.29 per kWh remaining hours 7 days per week

No.	***How do customers Pay for EV Charging?***
199	Level 2: $0.34 per kWh
200	$3.33 per hour
201	$1 initiation fee + $1.15 per hour
202	Free for guests; $0.11 per kWh for visitors
203	$0.15 per kWh for the first two hours of use; $1.50 per hour after first two hours of use
204	$0.15 per kWh for the first two hours of use; $1.50 per hour after first two hours
205	$2 per hour; $3 per hour when not charging
206	$0.45 per hour
207	$3 month or hourly garage rate
208	$3 per month or hourly garage rate
209	$3 per hour or garage rate
210	$1.00/hr parking fee
211	$0.00–$1.00/hr variable parking fee
212	$0.00–$0.75/hr variable parking fee
213	$0.00–$10.00/hr variable parking fee
214	$2.00/hr parking fee
215	$1.70/hr parking fee
216	$1.75/hr parking fee
217	$1.50/hr parking fee
218	$0.00–$2.00/hr variable parking fee
219	$0.35/hr parking fee
220	$0.00–$5.00/hr variable parking fee
221	$0.00–$1.50/hr variable parking fee; $0.15/kWh energy fee
222	$2.00–$3.00/hr variable parking fee
223	$0.00–$3.00/hr variable parking fee
224	$1.00–$5.00/hr variable parking fee

No.	How do customers Pay for EV Charging?
225	$1.50–$5.00/hr variable parking fee
226	$0.55–$15.00/hr variable parking fee
227	$0.20/kWh energy fee
228	$0.00–$10.00/hr variable parking fee; $0.08/kWh energy fee
229	$1.25–$5.00/hr variable parking fee
230	$2.00–$5.00/hr variable parking fee
231	$0.85–$5.00/hr variable parking fee
232	$2.00/hr parking fee; $0.12/kWh energy fee
233	$0.35/kWh energy fee
234	$1.00–$3.00/hr variable parking fee
235	$1.35/hr parking fee
236	$0.11/kWh energy fee
237	$0.00–$20.00/hr variable parking fee
238	$1.00–$4.00/hr variable parking fee
239	$1.00–$2.00/hr variable parking fee; $1.00/kWh energy fee
240	$0.00–$1.35/hr variable parking fee
241	$1.00–$10.00/hr variable parking fee
242	$1.50–$7.00/hr variable parking fee
243	$0.00–$8.00/hr variable parking fee; $0.13/kWh energy fee
244	$0.00–$1.00/hr variable parking fee; $0.15/kWh energy fee
245	$1.00–$8.00/hr variable parking fee
246	$1.00–$2.00/hr variable parking fee
247	$0.00–$15.00/hr variable parking fee
248	$0.06/kWh energy fee
249	$0.10/kWh energy fee
250	$1.99/hr parking fee

No.	How do customers Pay for EV Charging?
251	$0.00–$0.25/kWh variable energy fee
252	$0.99–$5.00/hr variable parking fee
253	$0.60–$2.00/hr variable parking fee
254	$1.75–$3.75/hr variable parking fee
255	$1.00/hr parking fee; $1.00/kWh energy fee
256	$0.00–$1.50/hr variable parking fee
257	$0.00–$3.00/hr variable parking fee; $0.00–$0.50/kWh variable energy fee
258	$0.00–$0.20/kWh variable energy fee
259	$0.50–$0.75/hr variable parking fee
260	$1.00/hr parking fee; $0.25/kWh energy fee
261	$0.50–$0.95/hr variable parking fee
262	$0.00–$5.00/hr variable parking fee; $0.20/kWh energy fee
263	$0.00–$5.00/hr variable parking fee; $0.15/kWh energy fee
264	$0.00–$1.80/hr variable parking fee
265	$0.00–$2.00/hr variable parking fee; $0.13/kWh energy fee
266	$0.07/kWh energy fee
267	$0.50–$1.00/hr variable parking fee
268	$0.15/kWh energy fee
269	$0.12/kWh energy fee
270	$0.00–$1.00/hr variable parking fee; $0.25/kWh energy fee
271	$0.00–$1.00/hr variable parking fee; $0.32/kWh energy fee
272	$0.00–$1.00/hr variable parking fee; $0.21/kWh energy fee
273	$0.23/kWh energy fee
274	$2.00–$6.00/hr variable parking fee
275	$0.00–$6.00/hr variable parking fee
276	$3.00/hr parking fee; $0.92/kWh energy fee

No.	How do customers Pay for EV Charging?
277	$3.00/hr parking fee
278	$0.00–$0.18/kWh variable energy fee
279	$0.32/kWh energy fee
280	$1.00–$1.75/hr variable parking fee
281	$0.00–$5.00/hr variable parking fee; $0.20–$0.25/kWh variable energy fee
282	$0.00–$6.00/hr variable parking fee; $0.00–$0.35/kWh variable energy fee
283	$0.00–$1.50/hr variable parking fee; $0.20/kWh energy fee
284	$0.00–$3.25/hr variable parking fee; $0.00–$0.25/kWh variable energy fee
285	$1.00/hr parking fee; $0.20/kWh energy fee
286	$0.15/hr parking fee; $0.15/kWh energy fee
287	$1.00–$3.50/hr variable parking fee
288	$0.75–$2.00/hr variable parking fee
289	$0.00–$25.00/hr variable parking fee
290	$1.50/hr parking fee; $0.05/kWh energy fee
291	$0.75–$5.00/hr variable parking fee
292	$0.50–$5.00/hr variable parking fee
293	$0.75–$3.00/hr variable parking fee
294	$0.75/hr parking fee
295	$5.00–$12.00/hr variable parking fee
296	$0.39/hr parking fee; $0.39/kWh energy fee
297	$0.10–$0.25/kWh variable energy fee
298	$2.50–$10.00/hr variable parking fee
299	$0.17/kWh energy fee
300	$0.50/hr parking fee; $0.20/kWh energy fee
301	$0.52/kWh energy fee
302	$0.00–$5.00/hr variable parking fee; $0.16/kWh energy fee

No.	How do customers Pay for EV Charging?
303	$2.00–$15.00/hr variable parking fee
304	$1.25–$4.00/hr variable parking fee
305	$1.00–$1.35/hr variable parking fee; $0.00–$0.20/kWh variable energy fee
306	$2.00–$8.00/hr variable parking fee
307	$6.00/hr parkingfFee
308	$0.00–$5.00/hr variable parking fee; $0.25/kWh energy fee
309	$0.00–$2.00/hr variable parking fee; $0.00–$0.14/kWh variable energy fee
310	$0.00–$4.00/hr variable parking fee
311	$1.25–$3.00/hr variable parking fee
312	$1.00–$7.00/hr variable parking fee
313	$1.50–$2.00/hr variable parking fee
314	$0.50/hr parking fee
315	$0.00–$5.00/hr variable parking fee; $0.00–$0.15/kWh variable energy fee
316	$2.50/hr parking fee; $2.50/kWh energy fee
317	$0.18–$0.68/hr variable parking fee
318	$1.00–$20.00/hr variable parking fee
319	$0.50–$1.75/hr variable parking fee
320	$0.50/kWh energy fee
321	$0.00–$10.00/hr variable parking fee; $0.25/kWh energy fee
322	$0.00–$0.15/kWh variable energy fee
323	$1.50–$10.00/hr variable parking fee
324	$0.29/kWh energy fee
325	$1.75–$2.50/hr variable parking fee
326	$2.00–$10.00/hr variable parking fee
327	$0.00–$40.00/hr variable parking fee
328	$0.00–$26.00/hr variable parking fee

No.	How do customers Pay for EV Charging?
329	$1.00–$15.00/hr variable parking fee
330	$0.25–$1.00/hr variable parking fee; $0.10–$1.00/kWh variable energy fee
331	Level 2: $0.25 per kWh
332	$1.00/hr parking fee; $0.10/kWh energy fee
333	$0.15/hr parking fee; $0.10/kWh energy fee
334	EV pay parking
335	Free for first 2 hours; $1 per hour thereafter
336	$10 per charge
337	Free for 1/2 hour
338	$0.20 per kW; $2.00 minimum
339	$0.15 per minute
340	$1.00–$5.00/hr variable parking fee; $0.22/kWh energy fee
341	$60/month for unlimited use
342	$1.50 per hour for first 2 hours; $2.50 per hour thereafter; minimum payment is $1.50; maximum payment is $8 per every 4 hours
343	$0.60 per kWh
344	L2: free; DCFC: free for 30 minutes
345	Free for first 3 hours; $3 per hour after
346	Level 2: $0.16 per kWh; DC Fast: $0.3 per kWh
347	3 hours free; $3 per hour
348	$1.60 per hour; 4 hour limit
349	$1.50–$2.50/hr variable parking fee
350	$1.25–$3.50/hr variable parking fee
351	$2.00/kWh energy fee
352	Level 2: $0.15 per 30 minutes
353	Free; GM vehicles only
354	$3 per hour from 8:00 a.m.–9:00 p.m.

No.	How do customers Pay for EV Charging?
355	Free for hotel guests; $25 for non-guests
356	Level 2: $1 initiation fee + $1.15 per hour; DC Fast $1 initiation fee + $0.32 per minute
357	L2: $1.50 per hour; DC: $0.35 per minute
358	Level 2: $1.50 per hour; DC Fast: $0.35 per minute
359	Free; for guest use only
360	Free for 0–30 mins; $0.30 per kWh for 30–75 mins; $1.00 per kWh after 75 mins
361	$0.25/kWh energy fee
362	$0.49/kWh energy fee
363	$0.00–$3.00/hr variable parking fee; $0.00–$0.20/kWh variable energy fee
364	$0.5 per hour suggested donation
365	$2.00/hr parking fee; $0.20/kWh energy fee
366	$0.18 per hour
367	$0.24 per kWh
368	$0.49 per kWh
369	$20 per hour
370	Level 2: $0.21 per kWh
371	$0.40 per kWh
372	L2: $1 initiation fee + $1.15 per hour; DC: $1 initiation fee + $0.32 per minute
373	L2: $1 initiation fee + $1.15 per hour; DC: $1 initiation fee + $0.32 per minute
374	L2: $1.15 per hour; DC: $1 initiation fee + $0.32 per minute
375	Free; pay lot
376	$5.00/hr parking fee; $0.20/kWh energy fee
377	$0.00–$4.00/hr variable parking fee; $0.00–$1.00/kWh variable energy fee
378	$2.40 per hour

No.	***How do customers Pay for EV Charging?***
379	In-store: $5 initial fee + $0.25 per minute; at pump: $12.50 per 30-minute session
380	$0.00–$1.00/hr variable parking fee; $0.17/kWh energy fee
381	Level 2: $0.79 per kWh
382	$1.25/hr parking fee
383	$1.00–$25.00/hr variable parking fee
384	Level 2: free
385	$0.00–$3.00/hr variable parking fee; $0.30/kWh energy fee
386	$0.00–$5.00/hr variable parking fee; $0.20-$0.30/kWh variable energy fee
387	$1.00–$2.00/hr variable parking fee; $0.17/kWh energy fee
388	$0.95/hr parking fee
389	$0.00–$2.00/hr variable parking fee; $0.00–$0.25/kWh variable energy fee
390	$1.00–$6.00/hr variable parking fee
391	$2 donation to begin charging
392	$0.21 per minute
393	Level 2: $0.45 per kWh
394	Free for guests; $15 for non-guests
395	Level 2: $0.32 per kWh
396	Level 2: $0.4 per kWh
397	$0.30/kWh energy fee
398	$0.2 per kWh
399	$1.50/hr parking fee; $0.25/kWh energy fee
400	$0.00–$2.99/hr variable parking fee; $0.00–$0.15/kWh variable energy fee
401	Level 2: $0.29 per kWh; DC Fast: $0.49 per kWh
402	$0.25 per minute
403	Level 2: $0.42 per kWh
404	Level 2: $9.99 per 0 seconds

No.	How do customers Pay for EV Charging?
405	$0.21 per min
406	$0.46 per kWh
407	$1.75/hr parking fee; $0.20/kWh energy fee
408	$0.30 per min
409	DC: $0.30 per minute; L2: free
410	$0.10 per kWh for staff; $0.20 per kWh for public
411	$0.10 per kWh for staff
412	$0.21 per kWh
413	Level 2: $0.35 per minute
414	Level 2: $0.01 per minute
415	$0.00–$25.00/hr variable parking fee; $0.00–$0.18/kWh variable energy fee
416	Free for first 30 minutes
417	$0.30/min
418	DC: $0.30 per min; L2: free
419	Free while shopping
420	$0.28/kWh energy fee
421	$1 per session
422	$0.07 per kWh
423	$0.12 per kWh
424	$4.39 per week
425	$3.25 per kWh
426	$0.00–$0.38/kWh variable energy fee
427	Initial fee: $0.50; rate: $0.24/kWh
428	$9 per hour
429	$2 for 30 mins; $20 for all day
430	$0.14 per kWh

No.	How do customers Pay for EV Charging?
431	$1.25 per hour + $1 transaction fee
432	$0.00–$4.00/hr variable parking fee; $0.25/kWh energy fee
433	$1 per hour + $1 to start
434	$1.35/hr parking fee; $0.28/kWh energy fee
435	$1.00
436	$0.35 per minute
437	$0.20 per kWh; minimum payment of $0.50
438	$0.07 per kWh fee; $1.33 per hour parking fee
439	$1.00–$3.00/hr variable parking fee; $0.20/kWh energy fee
440	Level 2: $0.33 per kWh
441	$2.00–$5.00/hr variable parking fee; $0.20/kWh energy fee
442	$2.00–$5.00/hr variable parking fee; $0.10/kWh energy fee
443	$1.75–$5.00/hr variable parking fee
444	$4.00/hr parking fee
445	Free for guests; $5 per hour for non-guests
446	Free for guests; $5 per session for non-guests
447	$1.50–$3.50/hr variable parking fee; $0.12/kWh energy fee
448	$5.00/hr parking fee
449	$1.50–$3.00/hr variable parking fee; $0.22/kWh energy fee
450	$1 per session; $0.5 per hour; $0.08 per kWh
451	Level 2: $0.27 per kWh
452	$1.00/Hr parking fee, $0.12/kWh energy fee
453	Level 2: $0.07 per minute
454	$1.50/hr parking fee; $0.15/kWh energy fee
455	$1.49/hr parking fee
456	$1.00–$5.00/hr variable parking fee; $0.15/kWh energy fee

No.	***How do customers Pay for EV Charging?***
457	Level 2: $0.08 per minute
458	$0.00–$3.00/hr variable parking fee; $0.00–$10.00/kWh variable energy fee
459	Level 2: $0.2 per minute
460	$2.00–$4.00/hr variable parking fee
461	$1.00–$5.00/hr variable parking fee; $0.25/kWh energy fee
462	Level 2: $0.02 per 30 seconds
463	$1.50–$3.00/hr variable parking fee
464	$0.39 per kWh
465	$1.00–$3.00/hr variable parking fee; $0.36/kWh energy fee
466	$0.50–$4.00/hr variable parking fee
467	$1.75–$4.00/hr variable parking fee
468	$0.00–$4.00/hr variable parking fee; $0.00–$0.30/kWh variable energy fee
469	$0.38/kWh energy fee
470	$2.50/hr parking fee
471	$0.00–$5.00/hr variable parking fee; $0.00–$0.25/kWh variable energy fee
472	$0.86/kWh energy fee
473	$1.50–$25.00/hr variable parking fee
474	$0.35 per kWh; parking fee
475	$3.00–$5.00/hr variable parking fee
476	$1.80/hr parking fee
477	$2.30/hr parking fee
478	$0.00–$4.00/hr variable parking fee; $0.15/kWh energy fee
479	$1.00–$2.00/hr variable parking fee; $0.15/kWh energy fee
480	$0.00–$2.00/hr variable parking fee; $0.16/kWh energy fee
481	$0.01/hr parking fee; $5.00/kWh energy fee
482	$1.50–$4.00/hr variable parking fee

No.	How do customers Pay for EV Charging?
483	$0.30–$0.50/hr variable parking fee
484	$2.50–$4.50/hr variable parking fee
485	$1.00/hr parking fee; $0.08/kWh energy fee
486	$0.00–$8.00/hr variable parking fee
487	$0.00–$2.00/hr variable parking fee; $0.00–$0.11/kWh variable energy fee
488	$0.00–$2.00/hr variable parking fee; $0.20/kWh energy fee
489	$1.50–$3.00/hr variable parking fee; $0.18–$0.22/kWh variable energy fee
490	$2.00/hr parking fee; $0.25/kWh energy fee
491	$2.00/hr parking fee; $0.50/kWh energy fee
492	$0.00–$0.50/hr variable parking fee
493	$1.00–$4.50/hr variable parking fee
494	$0.19/kWh energy fee
495	$0.25–$1.00/hr variable parking fee; $0.25–$0.50/kWh variable energy fee
496	$1.00–$3.00/hr variable parking fee; $0.25/kWh energy fee
497	$0.55–$1.00/hr variable parking fee
498	$0.00–$2.00/hr variable parking fee; $0.35/kWh energy fee
499	$0.00–$5.00/hr variable parking fee; $0.10–$0.12/kWh variable energy fee
500	$2.00–$2.25/hr variable parking fee;
501	$0.00–$5.00/hr variable parking fee; $0.11/kWh energy fee
502	$0.75–$1.50/hr variable parking fee;
503	$2.50–$3.00/hr variable parking fee;
504	$0.19–$0.25/kWh variable energy fee;
505	$1.30–$2.50/hr variable parking fee;
506	$0.50–$2.00/hr variable parking fee;
507	$1.60–$5.00/hr variable parking fee;
508	$0.00–$0.60/kWh variable energy fee;

No.	How do customers Pay for EV Charging?
509	$0.00–$1.20/hr variable parking fee;
510	$0.00–$10.00/hr variable parking fee; $0.39–$0.49/kWh variable energy fee
511	$1.00/kWh energy fee
512	$0.00–$2.00/hr variable parking fee; $0.00–$0.20/kWh variable energy fee
513	$0.00–$5.00/hr variable parking fee; $0.00–$0.50/kWh variable energy fee
514	$0.50–$1.00/hr variable parking fee; $0.50–$0.55/kWh variable energy fee
515	Level 2: $0.15 per kWh
516	$0.27/kWh energy fee
517	$0.00–$5.00/hr variable parking fee; $0.00–$0.40/kWh variable energy fee
518	$0.00–$0.75/hr variable parking fee; $0.09/kWh energy fee
519	Level 2: $0.3 per minute
520	Free for 30 minutes
521	$0.40/hr parking fee
522	$2.00/hr parking fee; $0.30/kWh energy fee
523	$0.00–$5.00/hr variable parking fee; $0.00–$0.20/kWh variable energy fee
524	$2.00–$15.00/hr variable parking fee; $0.21–$0.31/kWh variable energy fee
525	$13.80 per hour
526	$1.35 per hour
527	$16 per day
528	$0.88/hr parking fee
529	Level 2: $0.36 per kWh
530	$2.00–$5.00/hr variable parking fee; $0.12/kWh energy fee
531	$0.48/kWh energy fee
532	$0.18/kWh energy fee
533	$0.00–$2.00/hr variable parking fee; $0.10–$0.35/kWh variable energy fee
534	$0.00–$20.00/hr variable parking fee; $0.00–$20.00/kWh variable energy fee

No.	How do customers Pay for EV Charging?
535	$5.00–$15.00/hr variable parking fee
536	$0.24/kWh energy fee
537	$0.00–$5.00/hr variable parking fee; $0.21/kWh energy fee

2.2 Charging Infrastructure in Kansas

As shown in Figure 2.2, Kansas currently has 491 charging station locations (33 private and 458 public) with 1013 EVSE ports.

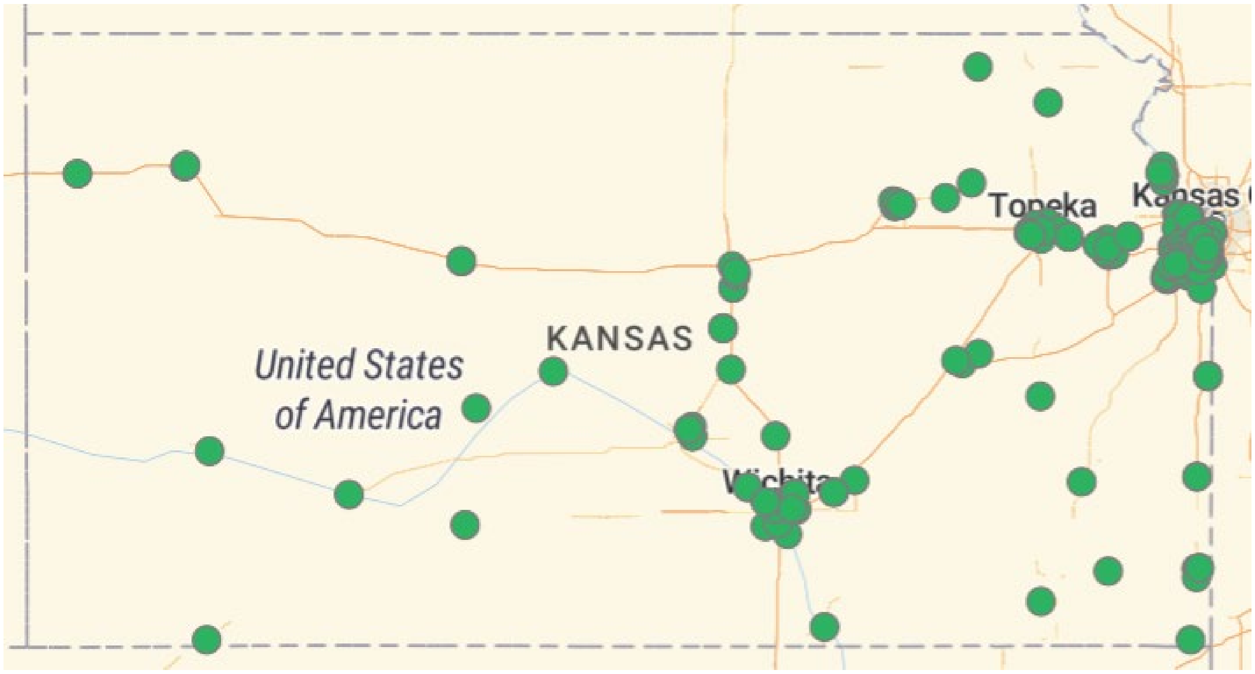


Figure 2.2: Charging Locations in Kansas

The charging price structure options in Kansas are free/no charge (primarily at car dealerships and utility locations); $0.28 per kWh, $0.26 per minute above 60 kW, and $0.13 per minute at or below 60 kW; and $0.20 per kWh. Of the total 491 charging locations in Kansas, 35 are DC Fast charging, 453 are Level 2, and three station locations (all private) are Level 1. The distribution of station location by type is shown in Figure 2.3 (409 locations have no information).

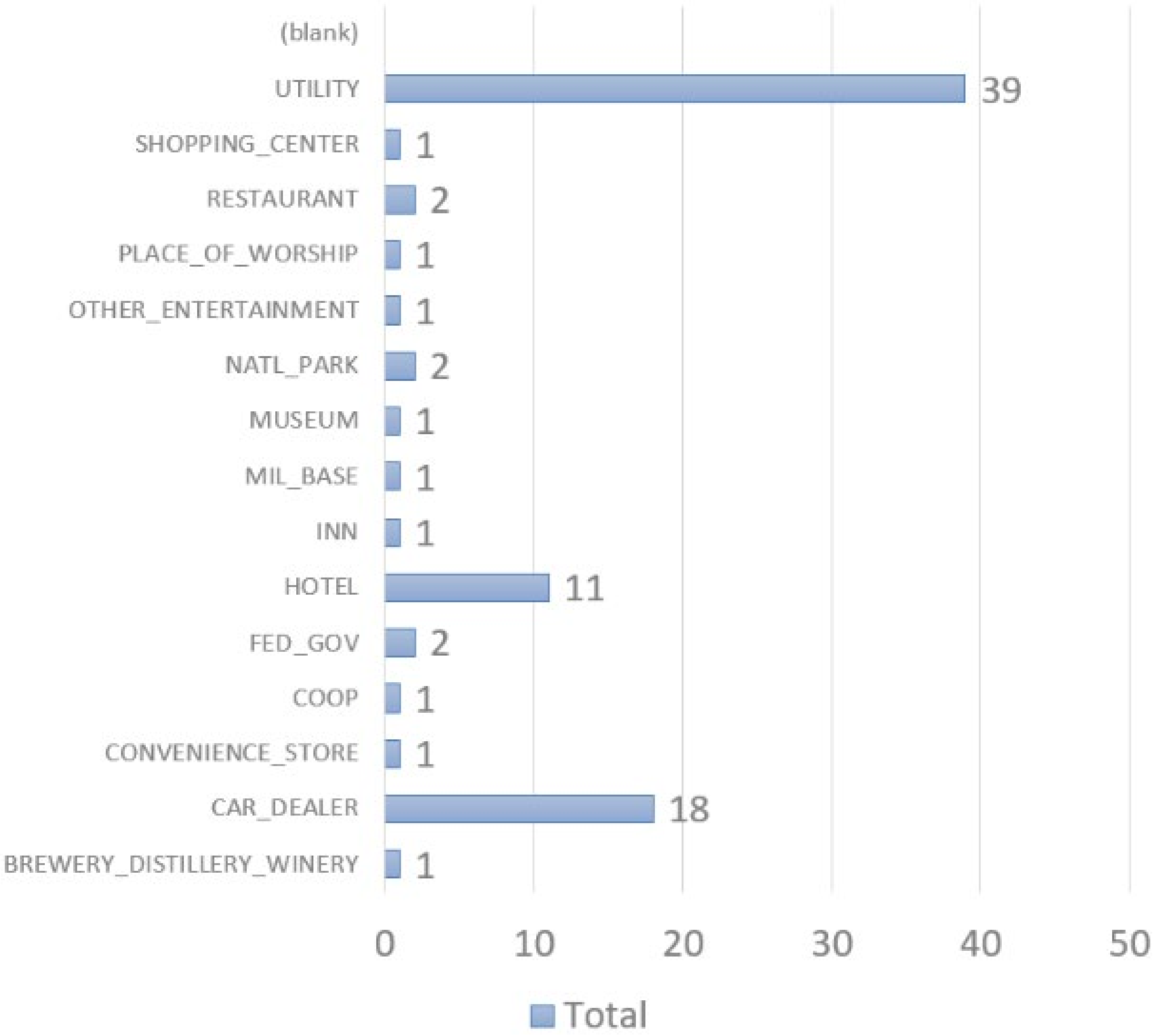


Figure 2.3: Distribution of Charging Location Type in Kansas

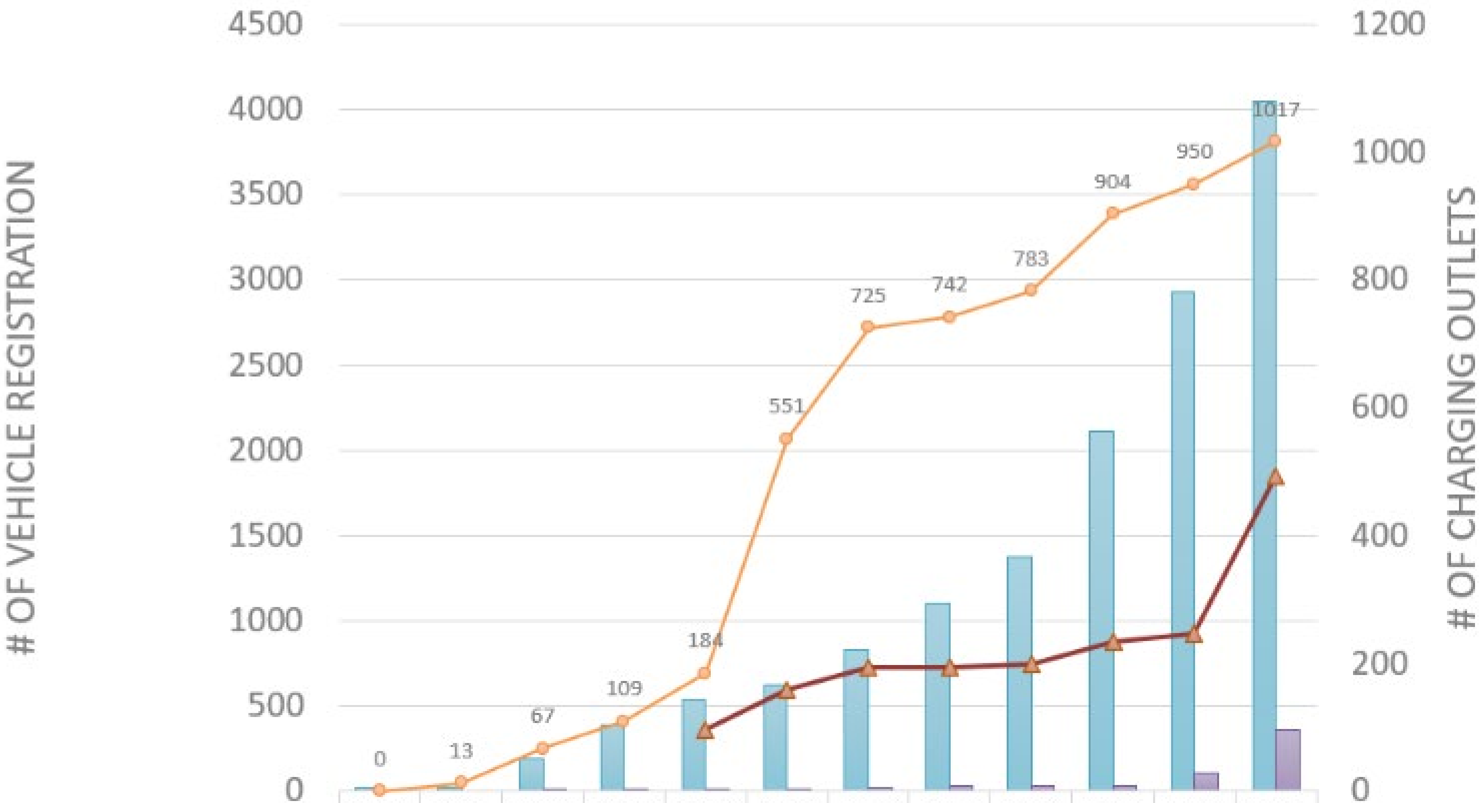
Chapter 3: Effects of Charging Infrastructure and Gasoline Price Variation on PEV Adoption

This section reports the outcome from **Task 3** and **Task 4** of this project. As mentioned, the primary research goal of this study was to identify the correlation between charging station availability and PEV adoption in Kansas using an EV market share model.

3.1 Charging Station Availability in Kansas

This study analyzed charging infrastructure availability in Kansas by extracting annual public station location data from the AFDC Alternative Fueling Station Locator. Figure 3.1 shows changes in the number of charging stations and outlets in Kansas from 2010 to 2021. Prior to 2014, the number of outlets was reported instead of the number of stations because no charging station counts data were available. The infrastructure data finally began to include charging levels (Level-1, Level-2, DC) in 2020. A positive correlation (Figure 3.1) was observed between the availability of charging infrastructure and the number of PEV registrations in Kansas. However, this study noted that the effects of recent increases in the number of charging stations may not be realized for several years, and pre- and post-pandemic impacts on PEV adoption, such as changes in affordability and overall travel patterns, must be accounted for.

Because the available AFDC data (Figure 3.1) reported only the aggregate number of charging stations for specific years, this study utilized charging location data for 2011 (7 stations), 2014 (97 stations), and 2021 (493 stations) to investigate county-level changes (see figures 3.2 – 3.4).



	2010	2011	2012	2013	2014	2015	2016	2017	2018	2019	2020	2021
BEV Registration	19	17	192	384	535	626	829	1102	1380	2107	2930	4046
PHEV Registration	0	0	11	16	16	14	22	27	30	33	108	359
# of Charging Outlets	0	13	67	109	184	551	725	742	783	904	950	1017
# of Charging Stations					97	158	195	194	198	234	246	493

Figure 3.1: Trends of PEV (BEV and PHEV) Registration and Availability of Public Charging Stations in Kansas (2010-2021)

3.2 Observations/Findings

As shown in Figure 3.1, even without the installation of new charging stations, a few Kansas counties increased PEV registration over time. For example, although Cloud and Ford Counties did not have any charging stations reported to AFDC for years 2011 and 2014, the data showed an increase in the number of PEV registrations in 2014 in these counties. However, the PEV registration number decreased for Cloud County in 2021, potentially in correlation with the charging infrastructure expansion. Cloud County reported no charging stations at the end of 2021, which could have discouraged PEV sales in that county.

Figure 3.1 also shows evidence of the neighboring effect for Kansas counties. For example, Jefferson County reported high numbers of PEV registrations even though no public charging station was recorded in the AFDC data. However, the neighboring counties—Shawnee, Douglas, Johnson, and Leavenworth—had many public charging stations with increasing availability over the years. The worker flow from Jefferson County may be well distributed to the neighboring counties with high charging station availability, thereby influencing the PEV adoption rate. Kingman County may demonstrate similar increasing PEV adoption without any charging infrastructure.

Figures 3.2–3.4 show the number of PEV registrations and charging stations by county in Kansas using R *Geostatistics* packages (*RGDAL, tigris, sf*) to map the geolocation of charging stations to corresponding counties. Figures 3.3 and 3.4 show that most charging stations are located in eastern Kansas, and the expansion pattern from 2014 to 2021 inclines toward eastern Kansas, potentially reflecting demand-based expansion strategies. The results show that only a few counties, such as Crawford, Bourbon, and Thomas Counties, exhibited increased PEV adoption over the data period.

The figures also reveal a higher adoption rate in urbanized areas than rural Kansas. For example, Kansas City (Kansas) and Wichita showed increasing numbers of PEV registrations from 2011 to 2021, as well as counties with university campuses, such as Riley County (Kansas State University), Saline County (Kansas State University Salina Aerospace and Technology), and Douglas County (University of Kansas).

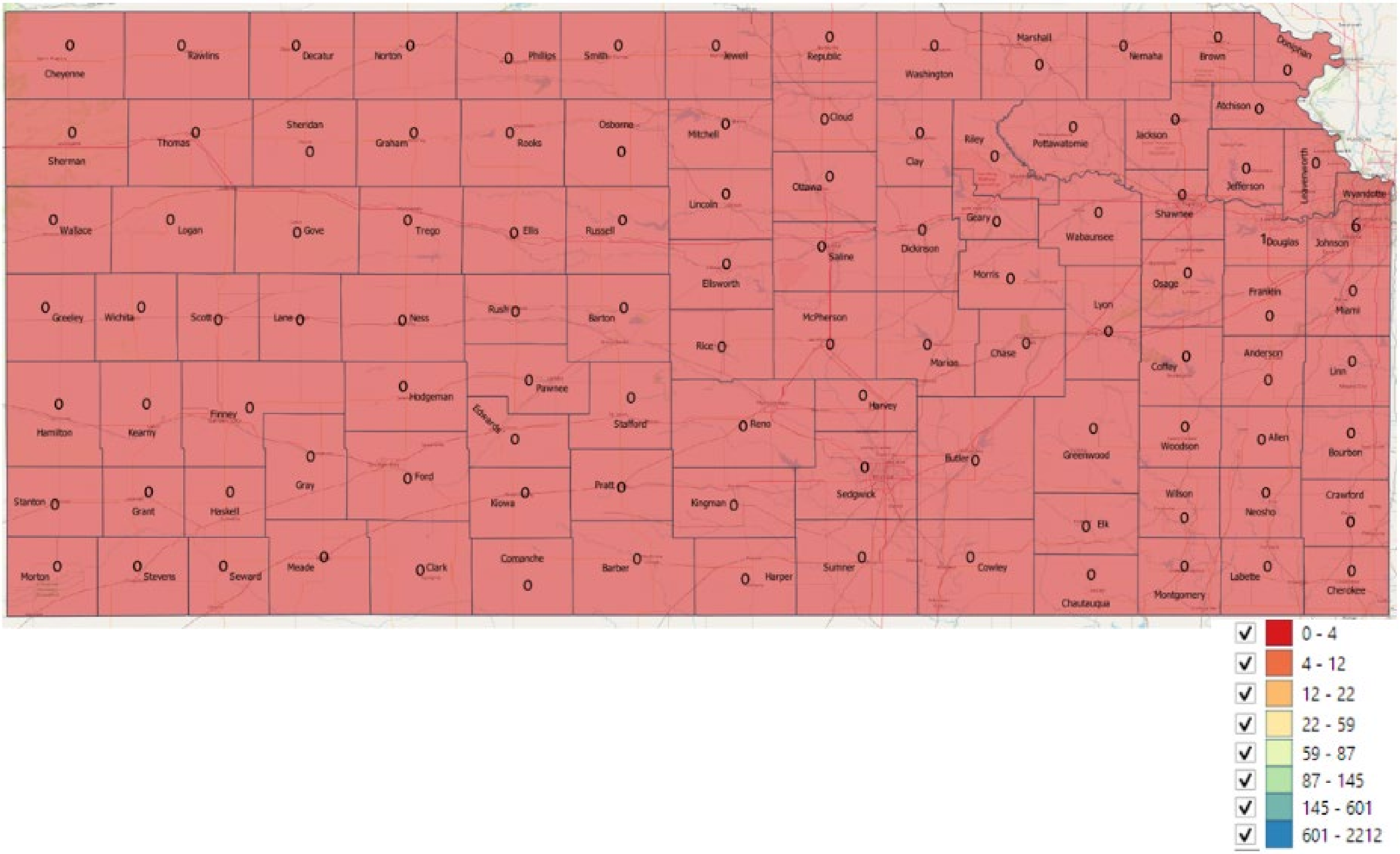


Figure 3.2: Numbers of PEV Registrations (Year 2011) by County with Number of Charging Stations (December 2011)

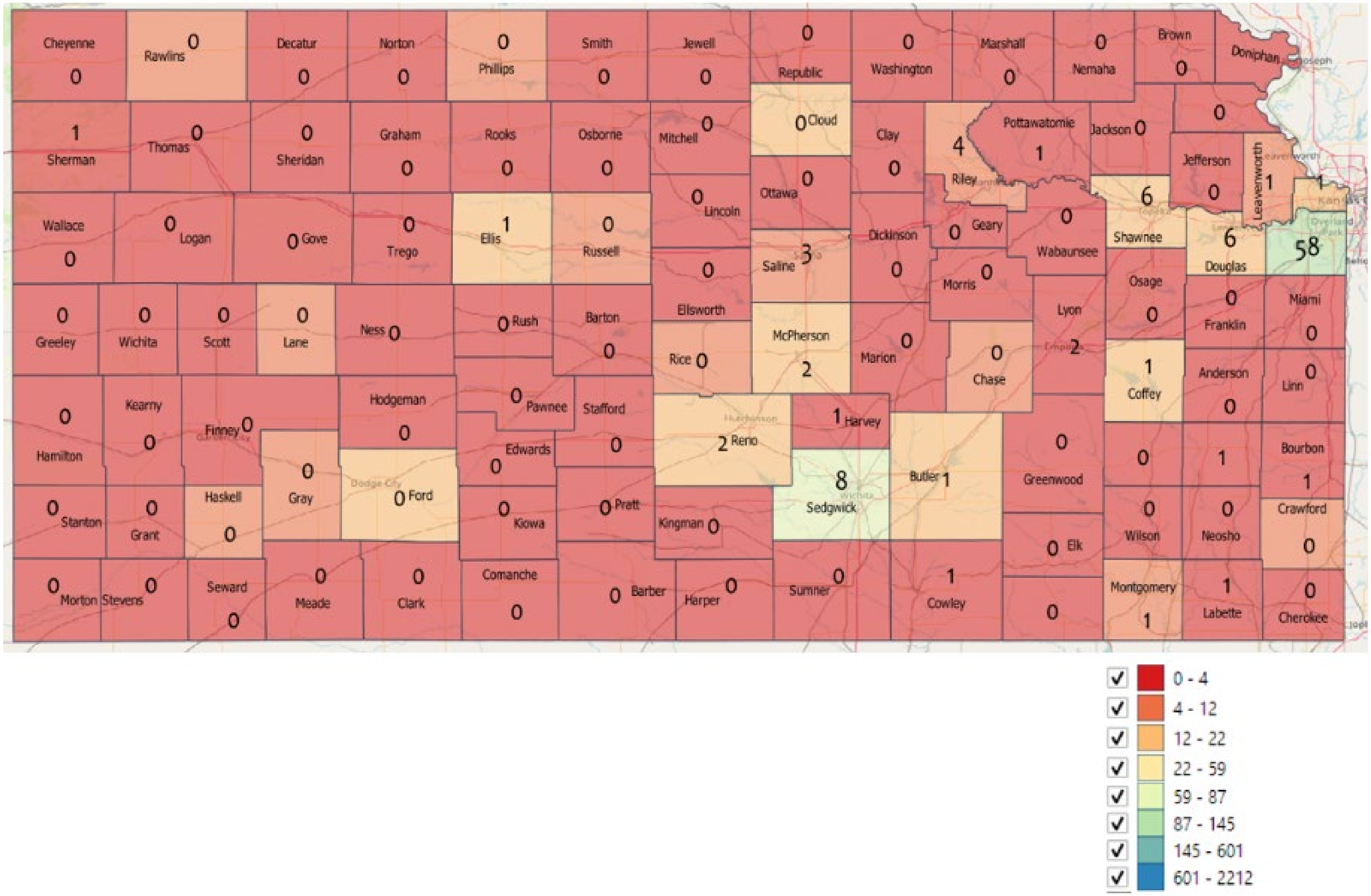


Figure 3.3: Number of PEV Registrations (Year 2014) by County with Number of Charging Stations (December 2014)

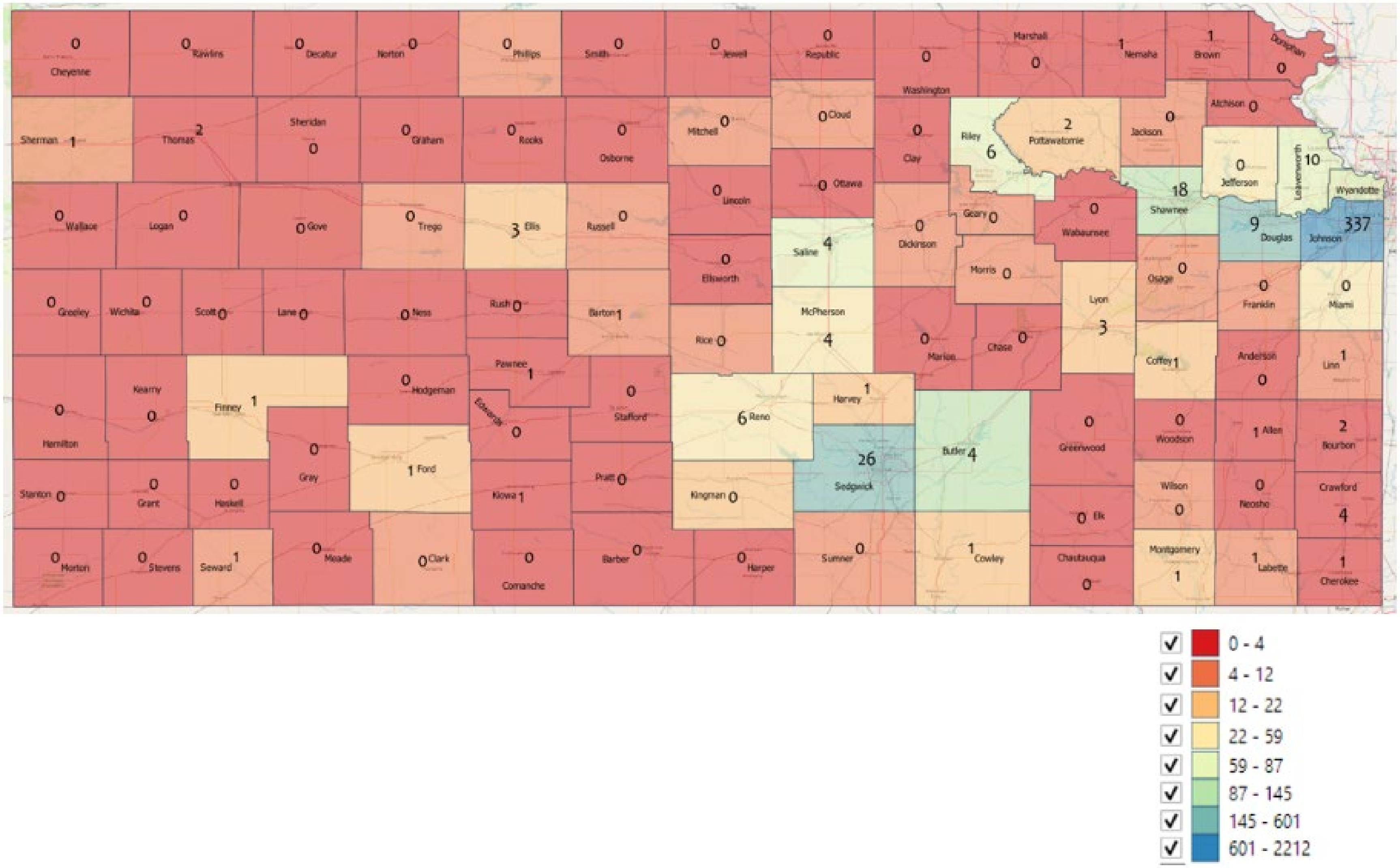


Figure 3.4: Number of PEV Registrations (Year 2021) by County with Number of Charging Stations (December 2021)

3.3 Effects of Public Charging Availability

The increased availability of public charging points and subsequent decreased stress of PEV users related to range anxiety, operational costs, and proximity to travel locations can increase PEV adoption (Loeb et al., 2018). However, public charging infrastructure expansion requires investment from public and private sectors and the effects of public charging availability are often not realized for several years. This study utilized the MA3T tool developed by the ORNL to analyze various scenarios (Lin et al., 2014; Lin & Greene, 2011). MA3T (Lin et al., 2013) allows users to build scenarios that focus on public charging availability throughout various geographic regions in the United States. The current version of the tool analyzes the years 2005–2050, with specific assumptions regarding technological advancement and EV adoption. The model is calibrated with 2017 data, including various assumptions for the adoption of AFVs. However, the level of complexities associated with consumer behavior and the dynamics of fuel prices, energy policies, and overall technology development cannot be represented with certainty within the MA3T tool.

Based on typical conditions and moderate availability of the charging infrastructure (2017–2050), MA3T offers baseline estimates of BEV adoption. Public charging availability is expressed as the percentage of areas with access to public charging infrastructure. MA3T also allows discrete input values at intervention points (years). From one intervention year to another, market share implementation was assumed to be gradual, and the availability of public charging was geographically categorized as Central City, Suburban, or Rural (Lin et al., 2013). The scenarios described in Table 3.1 emphasize rapid deployments of charging infrastructure and early public charging availability from the year 2025 in 3%, 5%, and 7% increments. The results compare only short-term projections of PEV sales for the years 2025–2030 due to rapid public charging infrastructure deployment. Base intervention years were 2005 (0%), 2011 (0%), 2017 (21%), and 2050 (42%). The scenarios indicated a faster deployment of public charging stations for 2022–2030.

Table 3.1: Scenarios for Public Charging Availability

Scenario-1 (Percentage of Areas with Access to Public Charging)			
Intervention Year	Central City	Suburban	Rural
2022	21	21	5
2025	24	24	8
2028	27	27	11
2030	30	30	14
Scenario-2 (Percentage of Areas with Access to Public Charging)			
Intervention Year	Central City	Suburban	Rural
2022	21	21	5
2025	26	26	10
2028	31	31	15
2030	36	36	20
Scenario-3 (Percentage of Areas with Access to Public Charging)			
Intervention Year	Central City	Suburban	Rural
2022	21	21	5
2025	28	28	12
2028	35	35	19
2030	42	42	26

According to Table 3.1, Scenario-1 showed a 3% linear increase from year 2022 to 2030 during a period of standard to moderate investment in electrification, Scenario-2 assumed moderate-to-fast, and Scenario-3 represented aggressive deployment of charging infrastructure with a 7% increase each year to reach 42%, which the base case predicted to be reached in 2050. Figures 3.5 and 3.6 show the projected PHEV and BEV sales, respectively, from MA3T scenarios.

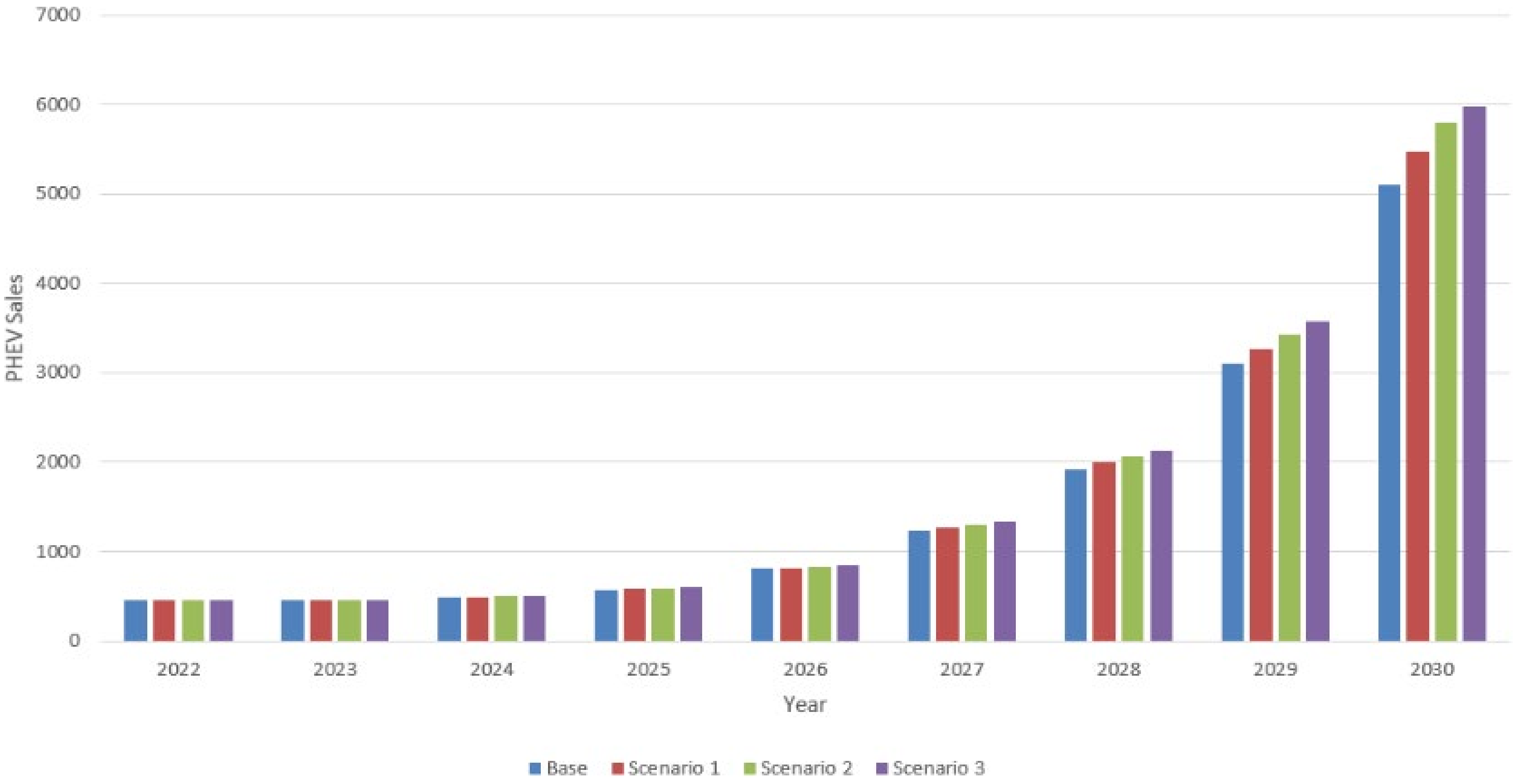


Figure 3.5: Projected PHEV Sales from MA3T (Charging Availability Scenarios)

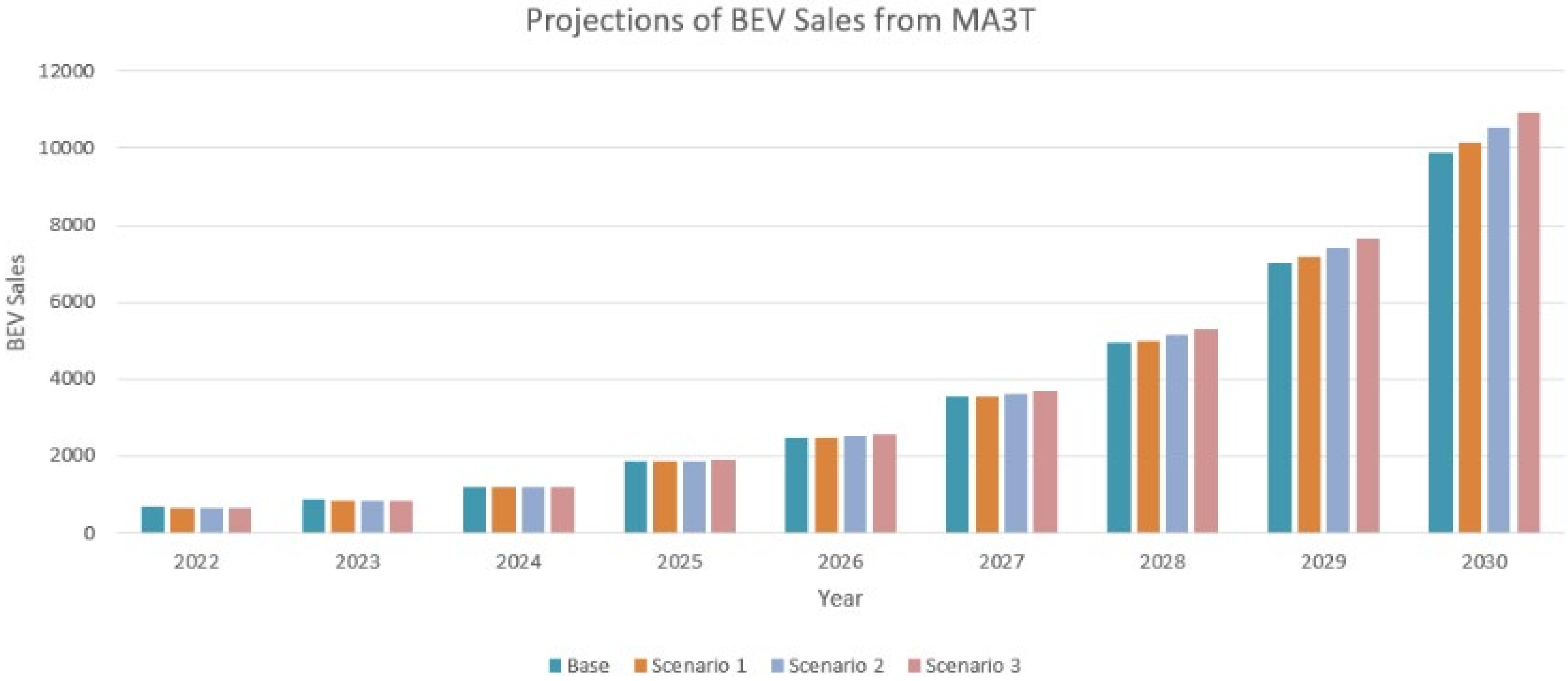


Figure 3.6: Projected BEV Sales from MA3T (Charging Availability Scenarios)

3.4 Effects of Reducing Residential Charging Installation

Because each hour of charging generally provides only 10–20 miles of range based on battery capacity and driving behavior, Level-2 AC charging installation (240 V) is not always affordable for EV owners at their residences. Costs for the installation of home chargers (with or without garages) vary, but MA3T assumes an average cost of $1000 for Kansas homeowners with garages and an average cost of $7000 for homeowners without garages in Kansas. One goal of this study was to project the changes in PEV sales as a function of reduced home charging installation costs, as described in scenarios in Table 3.2.

Table 3.2: Simulation Scenarios for the "Home Charge Installation Cost for Garage Homeowners" Variable

Scenario Name	**Description**	**Values used in the simulation (shown for Kansas only)**			
		With Garage (Area Type)	***Values Used (For 17-KS)***	***Without Garage (Area Type)***	***Values Used (for 17-KS)***
Base Scenario	In this scenario, the values used for this variable were unchanged from the default values of the MA3T model.	Central City	1000	Central City	7000
		Suburb	1000	Suburb	7000
		Rural	1000	Rural	7000
Scenario 1	In this scenario, values of different area types were reduced by 10% from the base values.	Central City	900	Central City	6300
		Suburb	900	Suburb	6300
		Rural	900	Rural	6300
Scenario 2	In this scenario, values of different area types were reduced by 20% from the base values.	Central City	800	Central City	5600
		Suburb	800	Suburb	5600
		Rural	800	Rural	5600
Scenario 3	In this scenario, values of different area types were reduced by 30% from the base values.	Central City	700	Central City	4900
		Suburb	700	Suburb	4900
		Rural	700	Rural	4900
Scenario 4	In this scenario, values of different area types were reduced by 50% from the base values.	Central City	500	Central City	3500
		Suburb	500	Suburb	3500
		Rural	500	Rural	3500
Scenario 5	In this scenario, more incentive was assumed	Central City	700	Central City	4900
		Suburb	700	Suburb	4900

	to be provided in rural areas. Values of Rural area types were reduced by 30% from the values presented in Scenario 3.	Rural	700	Rural	4900
Scenario 6	In this scenario, more incentive was assumed to be provided in rural areas. Values of Rural area types were reduced by 50% from the values presented in Scenario 4.	Central City	500	Central City	3500
		Suburb	500	Suburb	3500
		Rural	250	Rural	1750

Tables 3.3 and 3.4, as well as Figures 3.7 and 3.8, show the PHEV and BEV sales projections, respectively, from MA3T for scenarios described in Table 3.2. Results show that sales increase if home installation costs for Kansas decrease. Results also show that incentivizing rural home installation cost increases annual sales for both PHEV and BEV (Scenario 5 and 6).

Table 3.3: PHEV Sales from MA3T Scenarios for Garage Homeowners

Annual Sales Scenario	2022	2023	2024	2025	2026	2027	2028	2029	2030
Base Scenario	460	459	496	578	806	1234	1923	3103	5111
Scenario 1	481	480	518	604	842	1288	2008	3237	5326
Scenario 2	504	503	543	632	882	1349	2100	3384	5563
Scenario 3	530	529	570	664	926	1416	2203	3547	5825
Scenario 4	591	590	636	740	1032	1575	2449	3936	6448
Scenario 5	579	577	623	725	1010	1543	2400	3860	6329
Scenario 6	663	665	713	817	1102	1630	2476	3921	6343

Table 3.4: BEV Sales from MA3T Scenarios for Garage Homeowners

Annual Sales Scenario	2022	2023	2024	2025	2026	2027	2028	2029	2030
Base Scenario	671	870	1205	1870	2496	3531	4970	7043	9898
Scenario 1	695	902	1249	1939	2587	3659	5148	7292	10243
Scenario 2	722	937	1297	2013	2686	3797	5341	7562	10616
Scenario 3	752	975	1350	2094	2793	3948	5552	7857	11022
Scenario 4	820	1064	1471	2281	3041	4297	6037	8533	11950
Scenario 5	800	1038	1436	2229	2973	4203	5909	8357	11714
Scenario 6	860	1115	1543	2392	3190	4506	6330	8942	12513

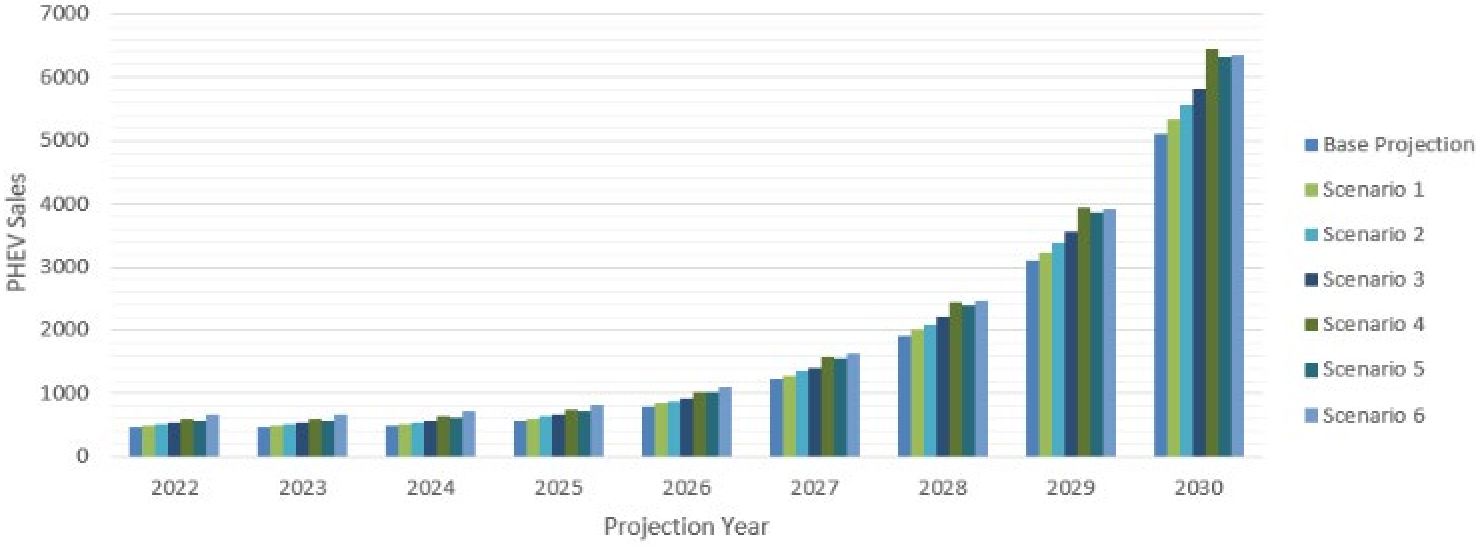


Figure 3.7: Projected PHEV Sales from MA3T Home Charging Installation Cost Scenarios

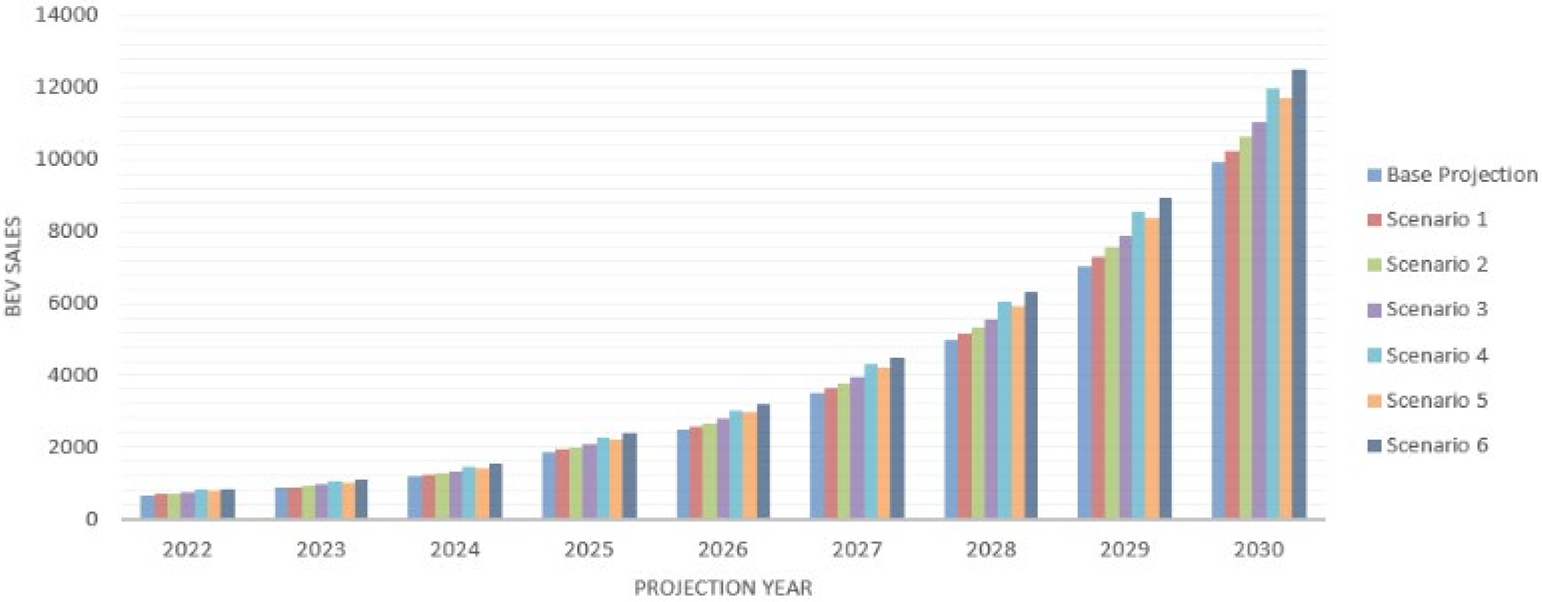


Figure 3.8: Projected BEV Sales from MA3T Home Charging Installation Cost Scenarios

3.5 Effects of Gasoline Prices

This study also examined the effects of variation in gasoline prices on PHEV and BEV adoption. MA3T divides the 51 states into eight groups, with Kansas in the West North Central region along with seven other states. For scenario analyses, this study assumed the gasoline prices of West North Central region to be representative of the state of Kansas, and a total of 10 case scenarios were tested. Table 3.5 provides scenario details, while Table 3.6 lists the various gas prices with the scenarios.

Table 3.5: Scenarios for Average Annual Fuel Prices

Scenario Name	Description
Base Case	Default settings of MA3T model
Scenario 1	5% increase in gasoline prices in the West North Central region from the year 2022 to 2050
Scenario 2	15% increase in gasoline prices in the West North Central region from the year 2022 to 2050
Scenario 3	25% increase in gasoline prices in the West North Central region from the year 2022 to 2050
Scenario 4	35% increase in gasoline prices in the West North Central region from the year 2022 to 2050
Scenario 5	35% increase in gasoline prices in the West North Central region in the year 2022 reflects the recent oil price surge ($3.687/gallon) due to the recent Ukraine-Russia conflict. The scenario is: After a 35% increase in oil price in 2022 to $3.687/gallon, from 2023 price will go down at a rate of 2% every year up to 2050.
Scenario 6	The scenario is: After a 35% increase in oil price in 2022 to $3.687/gallon, from 2023 price will go down at a rate of 5% every year up to 2050.
Scenario 7	The scenario is: After a 35% increase in oil price in 2022 to $3.687/gallon, from 2023 price will go down at a rate of 8% every year up to 2050.
Scenario 8	The scenario is: After a 35% increase in oil price in 2022 to $3.687/gallon, the price will increase at a rate of 2% until 2025, but from 2026 the price will go down at a rate of 2% on a yearly basis up to 2050.
Scenario 9	The scenario is: After a 35% increase in oil price in 2022 to $3.687/gallon, the price will increase at a rate of 5% until 2025, but from 2026 the price will go down at a rate of 5% every year up to 2050.
Scenario 10	The scenario is: After about 35% increase in oil price in 2022 to 3.687/gallon, the price will increase at a rate of 10% until 2025, but from 2026 the price will go down at a rate of 10% every year up to 2050.

Table 3.6: Fuel Price Data for the Scenarios

Scenario	2022 ($/gal)	2023 ($/gal)	2024 ($/gal)	2025 ($/gal)	2026 ($/gal)	2027 ($/gal)	2028 ($/gal)	2029 ($/gal)	2030 ($/gal)
Base Case	2.731	2.750	2.769	2.803	2.829	2.892	2.915	2.943	2.959
Scenario 1	2.867	2.888	2.907	2.944	2.970	3.037	3.060	3.090	3.107
Scenario 2	3.140	3.163	3.184	3.224	3.253	3.326	3.352	3.384	3.403
Scenario 3	3.414	3.438	3.461	3.504	3.536	3.615	3.643	3.679	3.699
Scenario 4	3.687	3.713	3.738	3.785	3.819	3.904	3.935	3.973	3.995
Scenario 5	3.687	3.613	3.541	3.470	3.401	3.333	3.266	3.201	3.137
Scenario 6	3.687	3.503	3.328	3.161	3.003	2.853	2.710	2.575	2.446
Scenario 7	3.687	3.392	3.053	2.748	2.473	2.226	2.003	1.803	1.622
Scenario 8	3.687	3.761	3.836	3.913	3.834	3.758	3.683	3.609	3.537
Scenario 9	3.687	3.871	4.065	4.268	4.055	3.852	3.659	3.476	3.303
Scenario 10	3.687	4.056	4.461	4.907	4.417	3.975	3.577	3.220	2.898

3.6 Findings

Tables 3.7–3.8 and Figures 3.9–3.10 show that annual sales of EVs have a significant positive correlation with future annual average gasoline prices. As the gasoline price increased, EV sales increased significantly from the base case. Results also showed that BEV sales increased more than PHEV sales. In scenarios 5–7, gasoline prices were assumed to decrease annually after the spike in 2022, so the EV adoption rate also decreased annually. In scenarios 8–10, EV adoption was highest for scenario 10 up to 2025 because gasoline prices in this scenario were assumed to increase by 8% yearly up to 2025. However, after 2025, scenario 10 produced a flatter EV adoption curve than the other two scenarios because the price of gasoline was assumed to decrease 10% annually from 2026. These results prove a high correlation of increased prices of gasoline with increased adoption of EVs, while low gasoline prices decreased the EV adoption rate.

Table 3.7: PHEV Sales for Scenarios of Average Annual Gasoline Prices for West North Central Region (Kansas)

Annual Sales Scenario	2022	2023	2024	2025	2026	2027	2028	2029	2030
Base	460	459	496	578	806	1234	1923	3103	5111
Scenario 1	499	497	535	623	867	1325	2057	3303	5404
Scenario 2	585	580	623	722	1000	1521	2340	3718	5999
Scenario 3	682	674	721	833	1147	1734	2643	4150	6598
Scenario 4	793	780	831	957	1308	1966	2964	4595	7193
Scenario 5	793	741	752	820	1077	1532	2263	3470	5484
Scenario 6	793	698	673	701	886	1218	1757	2650	4168
Scenario 7	793	658	581	563	672	883	1235	1829	2866
Scenario 8	793	800	873	1018	1318	1851	2694	4062	6294
Scenario 9	793	847	977	1199	1454	1930	2677	3881	5844
Scenario 10	793	930	1175	1569	1696	2039	2604	3536	5073

Table 3.8: BEV Sales for Annual Average Gasoline Prices for West North Central Region (Kansas)

Annual Sales Scenario	2022	2023	2024	2025	2026	2027	2028	2029	2030
Base	671	870	1205	1870	2496	3531	4970	7043	9898
Scenario 1	725	940	1300	2018	2691	3806	5346	7557	10583
Scenario 2	845	1094	1510	2339	3114	4400	6154	8654	12025
Scenario 3	981	1266	1745	2697	3583	5055	7035	9835	13553
Scenario 4	1132	1459	2006	3092	4098	5769	7985	11090	15151
Scenario 5	1133	1387	1819	2657	3364	4440	5945	8014	10800
Scenario 6	1133	1311	1632	2272	2754	3492	4522	5928	7835
Scenario 7	1133	1237	1412	1826	2077	2499	3113	3972	5171
Scenario 8	1133	1494	2104	3283	4132	5421	7198	9613	12802
Scenario 9	1133	1578	2344	3848	4566	5672	7159	9138	11705
Scenario 10	1133	1726	2800	4980	5334	6020	6965	8241	9910

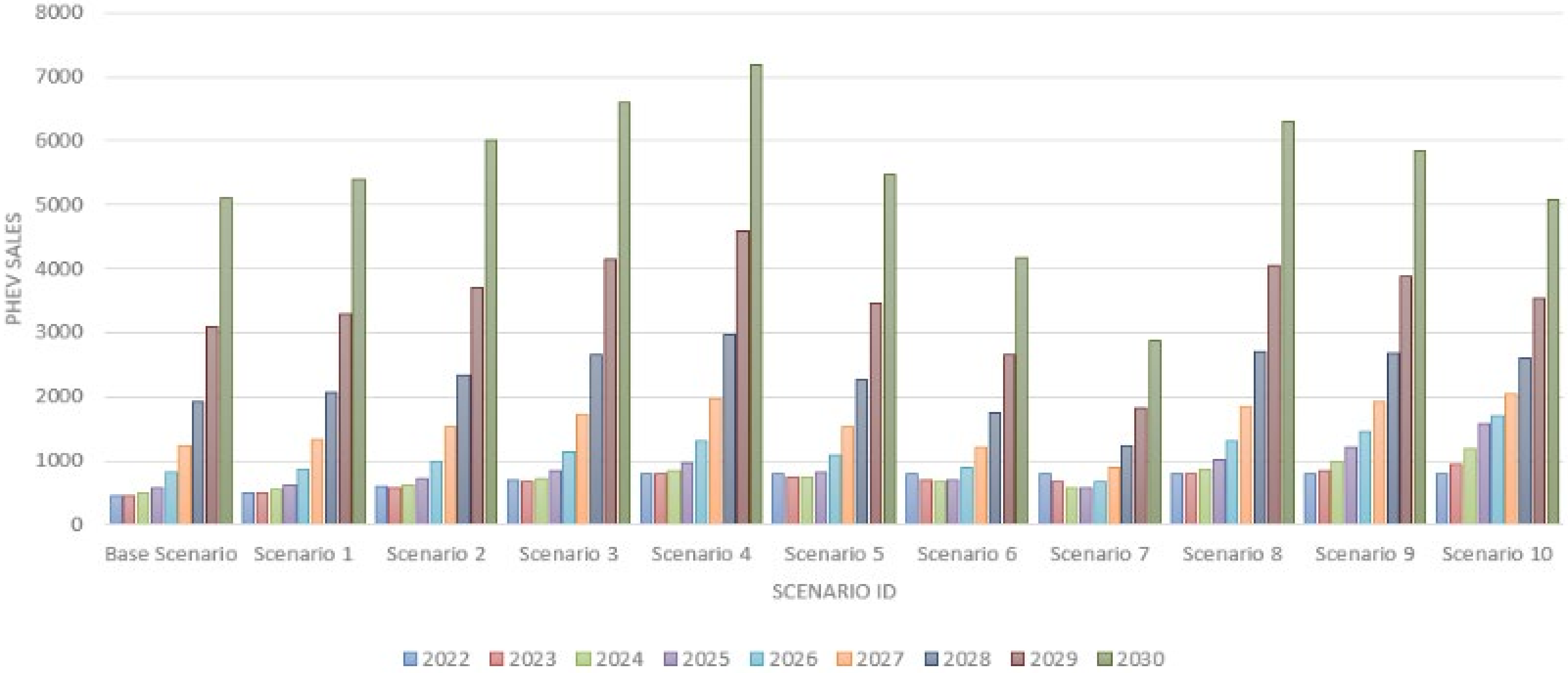


Figure 3.9: Projected PHEV Sales from MA3T (Gasoline Price Variation Scenarios)

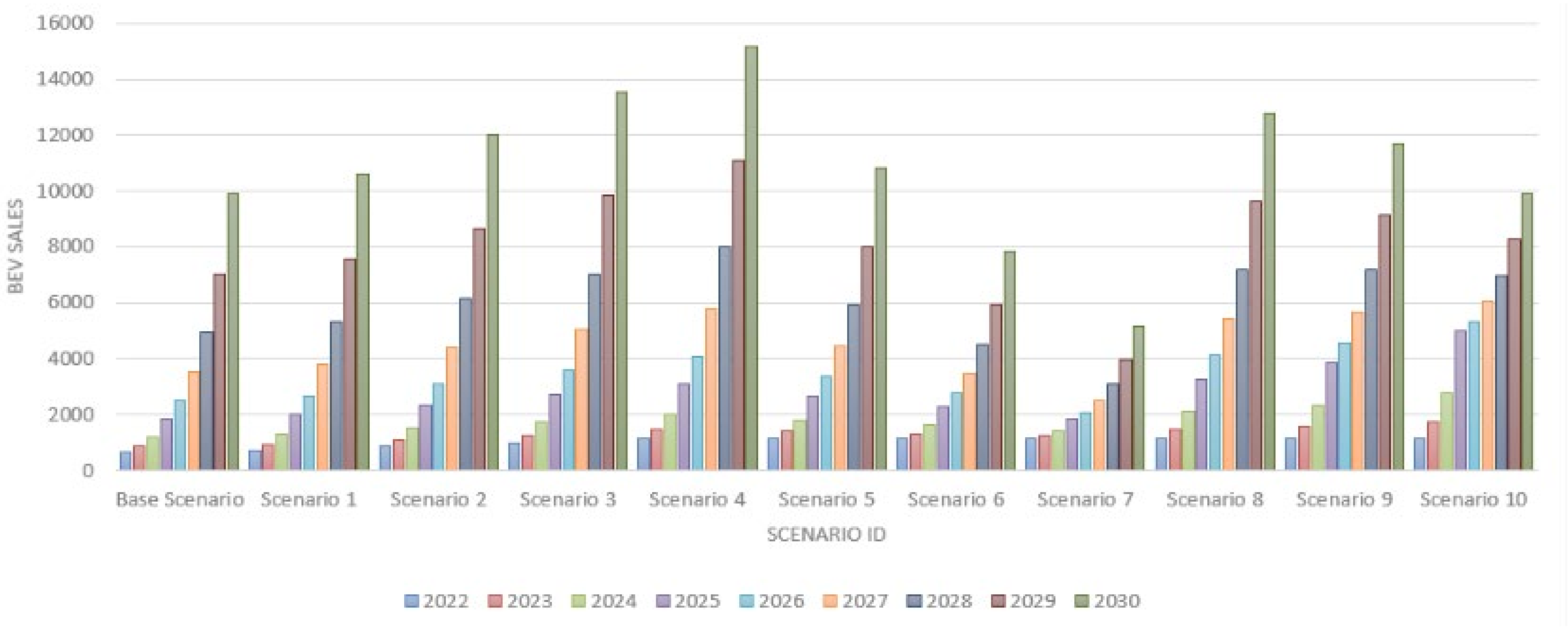
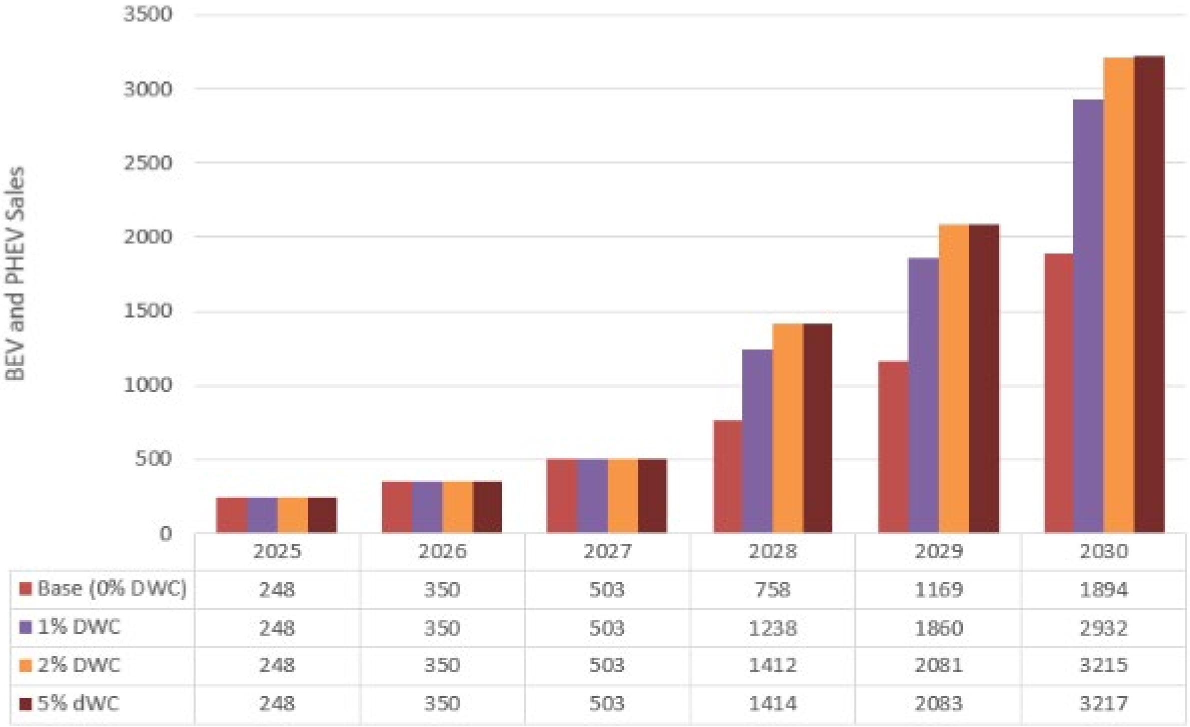


Figure 3.10: Projected BEV Sales from MA3T (Gasoline Price Variation Scenarios)

3.7 Effect of DWPT Implementation

The implementation of DWPT is expected to boost PHEV and BEV sales in the United States (Lin et al., 2014). Therefore, this study tested the effect of DWPT implementation, or the percentage of roads with DWPT capability (Figure 3.11). The MA3T tool has an infrastructure input option that allows the DWPT percentage for a specific state or geographic region. For Kansas, scenarios for 1%, 2%, and 5% DWPT were evaluated and compared to the base case, which had no DWPT implementation.



	2025	2026	2027	2028	2029	2030
■ Base (0% DWC)	248	350	503	758	1169	1894
■ 1% DWC	248	350	503	1238	1860	2932
■ 2% DWC	248	350	503	1412	2081	3215
■ 5% dWC	248	350	503	1414	2083	3217

Figure 3.11: Effects of DWPT Implementation on Combined PHEV and BEV Sales in Kansas

The results in Figure 3.11 indicate that DWPT adoption and its effects may take a few years. According to modeling methodology described in Lin et al. (2014), significant changes would only be expected in the year 2028, and it becomes marginal after the year 2029.

This study also tested hybrid scenarios. In Scenario-1, the DWPT opportunity function coefficients decreased by 3% from base values, and public charging availability coefficients increased by 3% from base values. In Scenario-2, DWPT opportunity function coefficients increased by 10%, whereas forecasted gasoline prices for the West North Central Region increased by 10%. Figure 3.12 shows the projections from MA3T simulation.

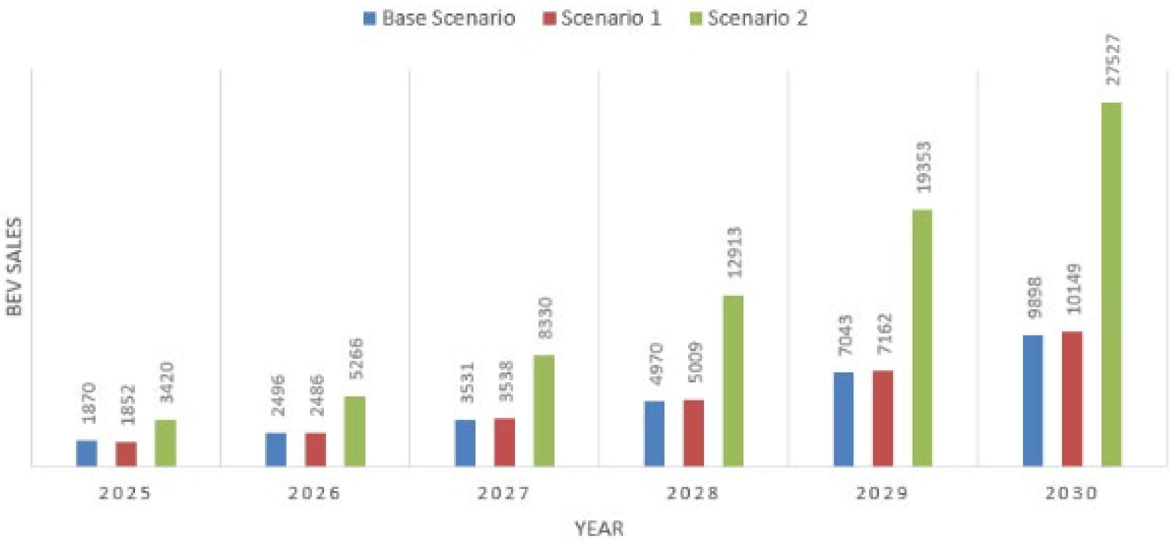


Figure 3.12: Effects of DWPT Implementation (Hybrid Scenarios)

Chapter 4: Economic and Financial Analysis

This section focuses on the **Task 5** of this project. The research objectives associated with this task included describing the costs associated with DWPT implementation, compiling the financial feasibility of DWPT deployment, and summarizing the pricing models.

4.1 DWPT Infrastructure Costs

Economic analyses are comprised of initial investment (capital/infrastructure) costs and operational and maintenance costs (Konstantinou et al., 2021). Unfortunately, Life Cycle Cost Analysis (LCCA), which refers to the costs associated with energy generation and transfer for DWPT deployments, is not common in the literature. However, several recent studies have estimated the costs for DWPT infrastructure while accounting for variation in specification and cost uncertainty, but the estimations assume technology availability and deployment feasibility, and most studies highlight the high initial cost of DWPT infrastructure construction and installation (Bi, 2018; Haddad, Arellano, et al., 2022; Konstantinou et al., 2021; Limb et al., 2016). Analyses based on deployment in Europe indicated high economies of scale and low marginal costs for DWPT installation (Börjesson et al., 2021; Limb et al., 2016).

4.2 Capital Investment

Capital costs include construction (pavement and power/electronics system), operations, maintenance, and contingency costs. Although the power-supply (electronics) system is sometimes considered a unified unit, component costs must be considered carefully for accurate analysis (Jang, 2018). This research synthesized existing studies (i.e., demonstration projects and experimental analyses) to investigate the expected costs and benefits of DWPT implementation. Research results briefly summarized the costs for components such as power transmitter systems, pavement/construction, and short- and long-term maintenance.

4.3 Electronics/Power Supply

The power transmitter system is typically built based on the power required by DWPT users (e.g., 50 kW for Light-Duty-Vehicles, and 200–250 kW for Heavy-Duty-Vehicles), meaning the system design varies based on materials and specifications. Common elements include power supply, the rectifier, the inverter, controllers, and charging pads. Previous studies have identified several configurations and the component details for each type (Choi et al., 2015; Jang, 2018; Miller et al., 2015; Trinko et al., 2022). Trinko et al. (2022) analyzed the costs of "1st-of-a-kind" (near-term-deployment) and "nth-of-a-kind" (assuming economies of scale and cost reduction) electronics systems based on DWPT deployment on the I-710 corridor (34-km segment in Los Angeles, California). The transmitter pad contained Litz wire coils comprised of thousands of thin, insulated strands and ferrite bars that shape the magnetic field. The length of the transmitter pad was 4.0 m, and roadside converters that provided DC output were positioned each mile. Also, the design included an inverter to convert the DC power to the desired frequency (85 kHz). The estimated cost for this DWPT electronics system was approximately $2 million per lane-km of near-term deployment with no technology or economies-of-scale discounts. Another estimate was made for the "nth-of-a-kind" system, assuming a cost reduction, such as use of photovoltaic components, resulting in an estimated long-term cost of $1.66 million per lane-km. A sample cost breakdown is shown in Table 4.1 (Trinko et al., 2022).

Table 4.1: Cost Breakdown of Electrical System

Components	Cost Per Module	Cost Per Lane-km
DC Inductor	$460	$115k
AC Inductor	$140	$35k
Series Tuning Cap Bank	$950	$238k
85 kHz Inverter	$4560	$1.14M
Charging Pad	$1880	$470k
Total	$7990	$2.00M

4.4 Construction/Pavement-Related Costs

Implementation of DWPT assets into the roadway requires a complete roadway design, including retrofitting the existing pavement and placing the power transmitter systems. Similar to the electronics system design, the AECOM design specification provides estimates for two cases: "1st-of-a-kind" and "nth-of-a-kind" (Konstantinou et al., 2021; Trinko et al., 2022). The first case implants precast Portland cement concrete (PCC) panels reinforced with rebars and dowel at joints with the DWPT electronics system with components described in Section 4.3. To retrofit the pavement and install the DWPT, the top layer was removed via saw-cutting and demolition, and then the precast PCC panels were installed, followed by the excavation and hauling of materials, excess-haul, stabilization of coarse aggregates, and hauling the PCC panels to the site. Costs associated with materials, labor, engineering design hours, inspection, accounting, administrative, and contingency (buffer) also must be considered. A high contingency cost (approximately 30%) results in a pavement installation cost of approximately $4.51 million per lane-km. However, optimized roadway design can decrease that cost. The "nth-of-a-kind" alternative can mill the existing surface, and the PCC panels can be cast-in-situ instead of prefabricated panels, thereby decreasing the cost to $1.09 million per lane-km. A sample cost breakdown table is provided in the appendix (Trinko et al., 2022).

Table 4.2: Cost Breakdown of Pavement-Related Costs

Cost Description	Cost Per Lane-km
Pavement Removal	$106k
WPT Embedded Pavement	$1.27M
Electrical	$727k
Signage	$12k
Indirect Costs	$541k
Soft Costs	$820k
Contingency	$1.04M
Total	$4.51M

4.5 Operations and Maintenance Costs

The maintenance costs of DWPT systems are primarily derived from elements of the electronic system and the pavement components. Although previous studies have investigated the impact of DWPT systems on routine pavement maintenance (Bateman et al., 2018; Jeong et al., 2015; ORNL, 2021), the study of the long-term effects of DWPT on the structural integrity and durability of pavements still requires extensive off-road and laboratory testing, with specific focus on DWPT impact related to pavement type (e.g., flexible vs. rigid), construction methods (e.g., trench-based methods), and the type of DWPT systems to be installed. It important to account for the asphalt surfacing maintenance operations given the existence of DWPT installations, but the DWPT manufacturer and pavement maintenance authorities must coordinate to ensure the preservation of DWPT functionality and the standard maintenance quality of pavement surfacing procedures.

DWPT maintenance costs will vary depending on the system components. Because real-world deployment of DWPT is minimal, however, no specific generalized bounds are established. The in-road components of wireless charging systems such as Electreon and Bomardier’s PRIMOVE are expected to require no maintenance throughout their lifetime, while the in-road components of Alstom’s ground-based static recharge system (SRS) should require no maintenance for 20–30 years, or the duration of their design lives (Bateman et al., 2018). In contrast, Dongwon OLEV in-road components require maintenance every 10 years (Suh & Gu, 2011). Depending on the amount of traffic and the amount of wear and tear caused by vehicles, the expected lifespans of the ElonRoad (Connolly, 2016) and Elways (Amditis, 2019) systems are 10 and 20 years, respectively. Testing of the Electreon system revealed the possibility of reflective cracking and skid resistance problems primarily associated with the asphalt overlay. Therefore, use of a stress absorbance membrane interlayer (SAMI) between the DWPT and asphalt layer was suggested to prevent reflective cracking, and visual inspections for defective joints and skid resistance issues were recommended for jointed concrete components (Bateman et al., 2018; Trinko et al., 2022).

4.6 Benefits and Feasibility of a DWPT System

The benefits of a DWPT system include cost savings, including recouping initial investments, and positive environmental impacts. Cost savings for DWPT users include decreased fuel costs, travel-time savings (charging time), financial incentives related to EV purchase, and minimal maintenance costs. The LCCA for DWPT systems is complex and generally incorporates significant uncertainty. We do not focus on the LCCA in this chapter. This study initially focused on the overall financial feasibility of DWPT systems, including initial capital cost investments and fees imposed on DWPT users.

4.6.1 Financial Feasibility (Recouping Cost)

Previous studies have investigated potential business models of DWPT systems, including how users could be charged and how costs could be recouped (Haddad, Konstantinou, et al., 2022; Jeong et al., 2015; Trinko et al., 2022). Results show that user charges would be comprised of the energy cost (based on usage) and a service fee, which covers the operations and maintenance costs plus the recouping of initial investment. However, the user charge would vary depending on the energy source, such as distributed renewal energy versus standard utilities. A reasonable assumption for the energy cost, or fees per km or mile of charging, allows an optimal DWPT service fee to be determined. A critical assumption pertains to the DWPT lifespan because the assumed number of years of operation and the associated discount rate would directly impact customers' service fees. Trinko et al. (2022) provides detailed analyses for multiple scenarios, and similar analyses are included in Bi (2018) and Limb et al. (2016). Key differences between these analyses relate to assumptions regarding initial investment (capital) costs, the pay-back time, and user adoption of DWPT technologies.

Investment recoveries for DWPT adoption for light- and heavy-duty vehicles can be expedited with different adoption trajectories. Most studies (Haddad, Arellano, et al., 2022; Haddad, Konstantinou, et al., 2022) have concluded that LDVs alone may not lead to the successful deployment of DWPT in the United States. Although a critical mass of LDVs is required to adopt DWPT, the HDV market share will trigger the conditions to make initial investment financially feasible. Furthermore, the freight corridors may become more attractive for DWPT implementation than city arterials. The complex choice to adopt DWPT for specific roadways depends on unique traffic patterns, EV adoption in the region of interest, and existing and planned charging infrastructure (Jang, 2018; Jeong et al., 2015).

Although DWPT energy costs are generally assumed to be constant, these costs become significant when renewable energy systems (e.g., wind-based energy in Kansas) are introduced into the business model. For example, traditional and renewable hybrid energy can decrease customer costs and increase DWPT adoption. Except for scenario-based analyses, however, no real-world data are available to report the effectiveness of this approach. The spatial distribution of electricity generation units can also be varied to decrease customer costs. Similar to the distributed energy resources (DERs), road segments or subareas can be selected for optimum DWPT implementation based on location of the renewable energy resources (e.g., geothermal, hydro plant, photovoltaic, and wind) (Haddad, Konstantinou, et al., 2022; Jang, 2018). Further research is needed to quantify the direct impact of renewable energy integration.

4.6.2 Environmental Impacts

The energy and environmental-related impacts of DWPT are associated with uncertain short-term and long-term costs (Jang, 2018; Jeong et al., 2015; Trinko et al., 2022). Existing evaluation approaches include LCCA, Levelized Cost of Electric Roadway, integrated life-cycle cost and assessment models, and scenario-based analyses. Analyses include energy and emissions outcomes compared to static charging infrastructure with various adoption rates; scenario analyses for various transportation modes, including public bus systems (Bi, 2018) and interstate freight (Haddad, Arellano, et al., 2022); and life-cycle cost comparisons that account for battery production and the carbon footprint associated with rare-earth mineral extraction. For example, when Trinko et al. (2022) estimated the $\mathrm{CO_2}$ equivalent emissions for LDVs and HDVs using I-710 as a test corridor for the years 2020–2040, the results indicated that the DWPT-enabled system can lead to a 27% reduction in $\mathrm{CO_2}$ equivalent emissions for low-market adoption and a 60% reduction for high-market adoption models. Most studies conclude that this environmental impact is highly uncertain given the advance in battery technologies, future adoption of EVs, and the future growth of charging infrastructure.

4.7 Pricing Models

In addition to the basic pricing model (i.e., energy charge plus service fees), DWPT can be implemented into pricing models similar to the existing congestion pricing models that utilize first- and second-best pricing (Yang & Huang, 2005) and mileage-based user fees, or road-use charging models (Matthews et al., 2021; Sorensen et al., 2012). Gill et al. (2014) provides a general framework of a possible private-public partnership model, underscoring the complexity in dynamics among stakeholders such as utility companies, renewable energy generation entities, road authorities, and local transportation agencies. With the uncertainty associated with the Highway Trust Fund (HTF) and the future electrification of transportation systems, fuel-based taxes are expected to decline. Because EVs do not directly contribute to gasoline taxes, future compensation for the HTF is a looming question. An efficient and financially feasible DWPT implementation assist to solve this problem.

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