Research paper

Assessing highway revenue impacts of electric vehicles using a case study

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A B S T R A C T

Increasing electric vehicle (EV) adoption poses serious concerns about the long-term adequacy of highway revenues. This paper addresses not only the fuel tax revenue loss across all vehicle classes but also proposes alternative funding mechanisms to recover the loss. Data on average vehicle miles travelled per vehicle, fuel taxes, vehicle registrations, fuel efficiency and consumption are used. The case study location is Indiana, U.S., and analysis period is 2021–2035. The optimal annual fees to recover the loss for each battery EV class range from $241 (in 2021) to $342 (in 2035) for automobiles, $344 to $435 for light-duty trucks, $1246 to $1488 for buses, $969 to $1243 for single-unit trucks, $6192 to $7321 for combination trucks, and $26 to $35 for motorcycles. For the most likely scenario (5% EV market penetration (EVMP) for light-duty vehicles and 30% EVMP for medium-/heavy-duty vehicles), the statewide fuel tax revenue decreases by 21% from 2030 to 2035. The paper also discusses a vehicle-miles-travelled fee and a pay-as-you-charge fee. The study framework is designed to facilitate replication in other states, and the results can provide useful information for assessing the adequacy of the existing revenue models and efficacy of prospective mitigation measures.

1. Introduction

In the United States (U.S.), there exists a wide variety of public and private revenue sources for highway funding. In particular, to fund highway spending, revenue is raised from user charges (motor fuel taxes, motor vehicle taxes and fees, and tolls), accounting for 44% of total federal, state and local revenue, as well as several other or non-user sources (General Fund appropriations, other taxes, investment income, and debt financing) (FHWA, 2014). Highway user charges constitute the largest part of revenue that state governments raise (around 56%), with motor fuel taxes accounting for 46% of the state revenue from user charges (FHWA, 2014). The importance of user charges for road infrastructure funding has been highlighted in numerous earlier studies (American Planning Association, 2010; Berg, 1990; Coussan & Hicks, 2009; Varma & Sinha, 1990; Watts et al., 2012). The effectiveness of any revenue source can be influenced by factors including vehicle fuel efficiency, attractiveness of alternative fuels, price inflation, and shifts in federal-state cost shares on infrastructure spending (Varn et al., 2020). Of these factors, the promotion of alternative fuels and more specifically, battery electric vehicles (EVs) continues to pose significant concern to highway revenue administrators, as they cause reduced

receipts from the fuel tax. This issue serves as the focus of this paper.

The fast-growing market share of EVs (IEA, 2022) is being catalyzed by favorable government policy, falling EV purchase prices, and increases in the number and types of EV models available to customers (Bräunl et al., 2020; IEA, 2019). This exacerbates the disquiet among highway revenue managers regarding the falling fuel tax revenues and consequently, the growing funding inadequacy for highway infrastructure improvements (Brown et al., 2020; Ford, 1995; Valenta, 2013; Varn et al., 2020). Clearly, as much as vehicle electrification is touted widely for its beneficial impact on the environment, EVs tend to be heavier compared to conventional vehicles, potentially affecting their contribution to road damage. It is also prudent for agencies to recognize the magnitude of the impact on highway revenues. As such, highway transportation agencies seek to ensure that the long-term transition to zero-emissions mobility can be achieved without compromising the adequacy of highway revenues.

In efforts to enhance highway agencies' preparedness for such uncertainty in the future of highway transportation funding, an important step is to identify the revenue "threat" posed by battery EV adoption and to measure their impacts. Another key step is to identify alternative mechanisms to recover the fuel tax revenue loss engendered by growing

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vehicle electrification. The existing literature on highway revenue loss estimation due to EV adoption focuses mainly on light-duty EVs. Several vehicle manufacturers though have indicated plans to introduce medium- and heavy-duty EVs to the market soon (e.g., BYD, 2020; Daimler, 2020, 2021; GM, 2021; Lambert, 2018; Lion Electric, 2021; Manthey, 2021; Matousek, 2018; Peterbilt, 2021; SEA Electric, 2019; Stinson, 2020; Tomlinson, 2020; Volvo, 2021). These vehicles, similar to light-duty EVs, are expected to have significant adverse impacts on highway revenue generation, since they contribute a large percentage of the total revenue from highway user charges. For instance, in 2019, trucks contributed around 53% of federal revenue and 41% (ATA, 2020) of state revenue raised from highway user charges (FHWA, 2019). Additionally, most past studies did not address alternative road-user pricing mechanisms to recover the lost revenue, such as electricity-use fees and/or vehicle-miles-travelled-based fees. This paper focuses on the impact of battery EV adoption on state fuel tax revenue, as fuel-related taxes account for, by far, the largest percentage of state highway revenue, and seeks to address the aforementioned gaps. In particular, it assesses the revenue loss for all vehicle classes and examines alternative user fee mechanisms to recover the revenue loss.

2. Existing literature on EV revenue recovery approaches and revenue impact assessment

Most countries provide incentives to encourage EV adoption and consider alternative ways to pay for transportation infrastructure in response to the growing demand for EVs. In the U.S., to recover the revenue loss, most states apply a state-level separate registration fee for EVs which is supplemental to the standard vehicle registration fee (NCSL, 2022; Short & Crownover, 2021). The fees range from $50 per year in Colorado, South Dakota and Hawaii to $225 for a plug-in EV in Washington (NCSL, 2022) and are paid annually or every two years, depending on the state. In particular, South Carolina is the only state with a biennial fee for EVs. As an alternative to EV registration fee, certain states, such as Oregon and Utah, also provide the option of a vehicle-miles-travelled tax. Oregon's OreGo program was launched as a pilot program in 2015 and vehicles which participate in the program can pay a road usage charge of 1.8 cents/mile (NCSL, 2022; Whitty, 2007). Utah's road usage charge program involves a 1.52 cents/mile charge up to the additional flat fee amount. Moreover, in Pennsylvania, alternative fuel vehicles (including EVs), are subject to an alternative fuel tax which is imposed on these fuels at the same rate as gasoline and diesel on a gallon equivalent basis (Short & Crownover, 2021; Szybist & Harris, 2019). User groups, such as alternative fuel dealers of electricity or EV drivers who charge their EVs at home, are required to remit a monthly electricity tax ($0.0172 per kWh) to the Department of Revenue (Pennsylvania Department of Revenue, n.d.).

In other countries, greater emphasis is placed on providing incentives or policies for EV adoption, and EV fees meant to recover revenue loss have been suspended (Hauff et al., 2018; IEA, 2021; Macioszek, 2021). The interested reader may refer to IEA (2021) and Macioszek (2021) to learn more about the policies to promote EVs around the world. For example, Norway and England are among the countries that provide the highest number of financial incentives, and most incentives are associated with purchasing EVs. In China, examples of incentives include exemptions from fees for registering an EV, lower costs for or free parking, free chargers when buying an EV, and more. New Zealand focuses on strategically installing EV charging stations along main transport routes.

A number of previous studies have investigated the revenue impact of alternative-fuel vehicles, in general, and EVs, in particular. This section presents, in a reverse chronological order, past studies that have explored this impact and/or funding mechanisms for revenue recovery. Short and Crownover (2021) explored options for charging electric automobile users for their use of public roadways in the U.S. and estimated the cumulative impact of electric automobiles on the Highway

Trust Fund revenue from 2020 to 2029 as approximately $4.3B. The authors also discussed approaches to taxing EV users for road use, including state-level registration fees, vehicle-miles-travelled fees, and electric fuel taxes. With regard to the electric fuel tax, the authors estimated that a tax of $0.021/kWh is equivalent to what is paid through the existing federal fuel tax on gasoline ($0.184/gallon). Xu et al. (2020) developed a method to estimate appropriate annual registration fees for passenger electric and plug-in hybrid EVs in Alabama, and determined that an additional $181 registration fee per EV ($200 in total) will be sufficient to cover the gasoline tax revenue loss (due to EVs) per fiscal year, as the fee was expected to generate additional revenue of approximately $333Kfrom the 1840 EVs in that state, in 2019.

A report by Plug In America included a qualitative discussion on the prospective efficacy of EV registration fees, mileage-based fees, and fees per unit use of electricity to fund road construction and repair (Plug In America, 2020). According to that report, EV registration fees are not an appropriate solution because they can slow not only EV adoption but also the pace of EV cost reductions. The authors also determined that road user fees based on electricity use could pose challenges associated with home charging due to the difficulty of quantifying EVs' electricity consumption. As such, they recommended the use of dedicated meters or smart chargers. The authors argued that, of the revenue recovery initiatives, the mileage-based fee has a greater potential and could also be sustainable even with more widespread ridesharing or carsharing. They stated that this initiative could include congestion pricing to manage demand and also could address potential concerns regarding equity from locational (rural vs. urban) and socio-economic perspectives. Ricciuti (2020) evaluated the impact of light-duty EV sales on lost gasoline tax revenue for the 50 U.S. states over a ten-year period (2019–2028) and provided recommendations for gasoline tax revenue recovery. The results indicated that in all 50 states, the lost gasoline tax revenue could be overcome by imposing a yearly EV surcharge: from $80 (Alaska) to $320 (Pennsylvania). Harto and Baker-Branstetter (2019) compared existing or proposed annual EV fees with the gasoline tax, across the states in the U.S. The authors used the ratio of existing/proposed EV fees to a maximum justifiable fee, which was calculated as the highest EV fee that could be established in a state and provides the same revenue as the average conventional/gasoline vehicle.

Jia et al. (2019) evaluated the fuel tax revenue impact of EV adoption in Virginia, focusing on light-duty battery and plug-in hybrid EVs. The authors applied a county-level EV ownership model to predict EV counts in each county of the state from 2016 to 2025, created scenarios involving levels of fuel economy and adoption, and examined the spatial distribution of fuel tax revenue. Their results suggest a 5–19% drop in statewide fuel tax revenue in 2025 relative to 2016. From the spatial distribution of revenue, they showed that by 2025, vehicles in rural areas are likely to pay 28% more in fuel taxes compared to those in urban areas. Iowa Department of Transportation (DOT) (Iowa DOT, 2018) sponsored a study that examined existing and potential funding mechanisms in order to develop recommendations to lower administrative costs, promote equity, yield no net change in road use tax fund revenue and promote a constitutional provision that ensured the spending of some collected revenue on road and bridge maintenance and improvement only. The Iowa DOT report considered light- and medium-duty vehicles and the analysis was conducted for the 2018–2040 analysis period. The results showed that lost road use tax fund collections would be approximately $317K in the base year (2018). For a high EV market growth scenario, the authors projected that there will be a twenty-fold increase in the reduction of the state road use tax fund in just five years (2020–2025). Based on these results, the Iowa DOT proposed and qualitatively described three mitigation strategies: a per kilowatt-hour excise tax for charging at non-residential charging locations, a supplemental registration fee for passenger EVs, and a hydrogen fuel excise tax. Chamberlin et al. (2016) estimated statewide fuel tax revenue from light-duty EVs in Utah by 2040. To estimate the vehicle miles travelled, the fuel consumption and fuel tax revenues, the

authors used FHWA's Energy and Emissions Policy Analysis Tool and concluded that the fuel tax revenue will decline by 29% in 2040 compared to 2010.

Jenn et al. (2015) explored how different brands and models of EVs (light-duty EVs and automobile EV models (Toyota Camry, Honda Civic, Ford F-150, Nissan Leaf, Toyota Prius, Chevrolet Volt) could marginally impact the annual revenues at state and national levels. The study also attempted to estimate alternative policy options for EVs based on charging an annual registration fee, a use fee tax or a charging tax on electricity. The results suggested that the total annual revenue generation will decrease by about $200M to $900M by 2025, depending on the level of EV adoption. To mitigate the shortfalls in revenue generated, the authors proposed a flat annual registration fee at 0.6% of the vehicle's manufacturer suggested retail price, a 2 cents/mile fee, or a 4.5 cents/kwh tax. Schleith (2015) investigated the impact of light-duty EVs on highway revenue sources and found that the average gas tax revenue loss associated with U.S. light-duty EV sales of 365K vehicles was $71.9M or 0.23% (as of August 2015). Although the authors focused on fuel tax revenue, they also discussed alternative mechanisms such as tolls, replacing or adding to the fuel tax, and a vehicle miles travelled-based tax that accounts for vehicle type, weight, location, and time of roadway use.

Vasudevan and Nambisan (2014) examined the impacts of Corporate Average Fuel Economy (CAFE) regulations and variations in fleet adoption (for hybrid electric and alternative fuel light-duty vehicles and light trucks) on national transportation funding. The authors used the New Sales Survivability model and new vehicle sales and survivability data from 1980 to 2005 to estimate the fleet mix and vehicle miles travelled and make fuel tax revenue projections up to 2025. Different scenarios were considered to analyze the revenue impact implementation of regulations and introduction of hybrid or alternative fuel vehicles. Based on the implementation of CAFE regulations and the premise that new hybrid or alternative fuel vehicle sales will increase by 20% annually from the base year (2009), the authors projected that the federal fuel tax revenues will decrease by more than 31% (by introducing hybrid vehicles) and 37% (by introducing alternative fuel vehicles) in 2025. Also, the Oregon DOT conducted studies to explore various funding initiatives and examined potential implementation issues, including the case of "all-EVs". In Whitty (2007), the Oregon Mileage Fee Concept was examined and charged all automobiles approximately 1.8 cents/mile with approximately 40% of the revenue being paid to third-party technology companies that facilitate the program and not to the state (Short & Crownover, 2021). The study did not calculate the impact of EVs on state revenue but mentioned options for all-EVs to pay a mileage-fee. In Jones and Bock (2017), the results of the Oregon Road Usage Charge Program were presented. Among other options for conventional vehicles, ideas for EV fees, including flat fees, taxes on electricity for vehicle use, and fees based on distance travelled, were also examined. According to the authors, a key lesson from their pilot program is that charging road users per mile of travel is feasible, but they acknowledged the possibility of implementation challenges including communication difficulties between the mileage-reporting device and the EV.

These previous studies examined the revenue impacts of EV adoption either in a qualitative manner, or where quantitative analysis was used, this was done for light-duty vehicles mostly. However, the reality is that (a) quantitative research of a wider scope (all vehicle classes) is essential to easily understand and describe the magnitude of the EV impact comprehensively to decision makers, and (b) advancements in EV technology are not limited to light-duty vehicles only. Additionally, a majority of the past studies had focused mainly on policies related to fuel tax while transportation funding is (or could be) based on additional sources. Most studies did not address adequately alternative mechanisms, such as user fees for electricity use and/or vehicle-miles-travelled-based fees, with the exception of Jenn et al. (2015) and Short and Crownover (2021) who provided some quantitative

information of the impacts. The results of the literature review highlighted the need to present more well-documented and practical models for developing highway revenue estimates to inform highway transportation agencies and state legislatures.

3. Methods

The methodology of this study is designed to estimate the annual supplemental fee to be charged per EV to break even, that is, to recover the state fuel tax revenue loss that is associated with the EV adoption (this is referred to as the "recovery EV fee"). Fig. 1 illustrates the study methodology. The first output is the revenue loss per vehicle class (revenue that would be generated from EVs if they run on gasoline or diesel fuel). To determine this revenue loss, the annual (average) vehicle miles travelled (VMT) of EVs were estimated as the product of the annual VMT per vehicle and the number of EV registrations. For each year, the number of EV registrations were estimated as the product of the EV market penetration (EVMP) and the total vehicle registrations at that year. Taking the ratio of the estimated annual VMT of EVs by the fuel efficiency per vehicle class produces the amount of fuel (in gallons) that is not consumed (or, lost) due to the growth of EVs in the market. Next, the fuel tax revenue loss is estimated as the product of the amount of fuel that is lost and the fuel tax. The recovery EV fee that could make up the decrease in revenue generation is calculated by distributing the revenue loss to the EV registrations. The results are provided per vehicle class, and for the 2021–2035 analysis period. The vehicle classes considered are: automobiles, light-duty trucks, motorcycles, buses, single-unit trucks, combination trucks. These six vehicle classes form the following two main vehicle groups: (a) light-duty vehicles (automobiles, light-duty trucks and motorcycles) and (b) medium- and heavy-duty vehicles (buses, single-unit trucks and combination trucks). Note that the research framework to estimate the recovery EV fee can be expanded to also consider federal taxes.

Section 4 describes, in greater detail, the data needed to compute the annual loss in revenue. Projections for each future year are made based on available data sources or using predictive analysis of historical data, that is, trend analysis or an average (or flat) line. Scenario development related to future EVMP levels was also conducted and the impact on highway revenue was analyzed. The evolution of market penetration from 2021 to 2035 was based on the classic logistic S-curve. This methodology is in line with other studies that had used S-curves to predict market penetration of new technologies (e.g., Choi et al., 2013; Konstantinou, 2019; Trinko et al., 2022). The logistic curve is determined by specifying two coordinates (year, market penetration level) on the curve. The equation of the S-curve is as follows (Equation (1)):

$$f(t) = \frac{L}{1 + e^{-\alpha(t-t_0)}} \qquad \text{Equation 1}$$

where $f(t)$ indicates the market penetration value, L indicates the curve's maximum value or peak market share, t indicates the time (year), α is a parameter that stretches or compresses time and t_0 is a parameter that shifts the curve's timeline.

For each scenario, the fuel tax revenue loss, recovery EV fee per vehicle for each vehicle class, and fuel tax revenue were calculated for each year of the analysis period. A conceptual causal loop diagram (Fig. 2) was also developed to demonstrate the dynamics of the overall system (Labi, 2014). This diagram uses arrows as links to show the causal relationships between each pair of parameters. The arrows are annotated as positive or negative depending on the direction of influence of one parameter (the start of the arrow) relative to the other parameter (the end of the arrow). For example, an increase in the gallons lost due to the popularity of EVs is accompanied by an increase in the revenue loss. This figure also uses colors to follow the order of the calculations to estimate the final outcome. In particular, the first calculated parameter is the EV registrations that come from data on the EVMP
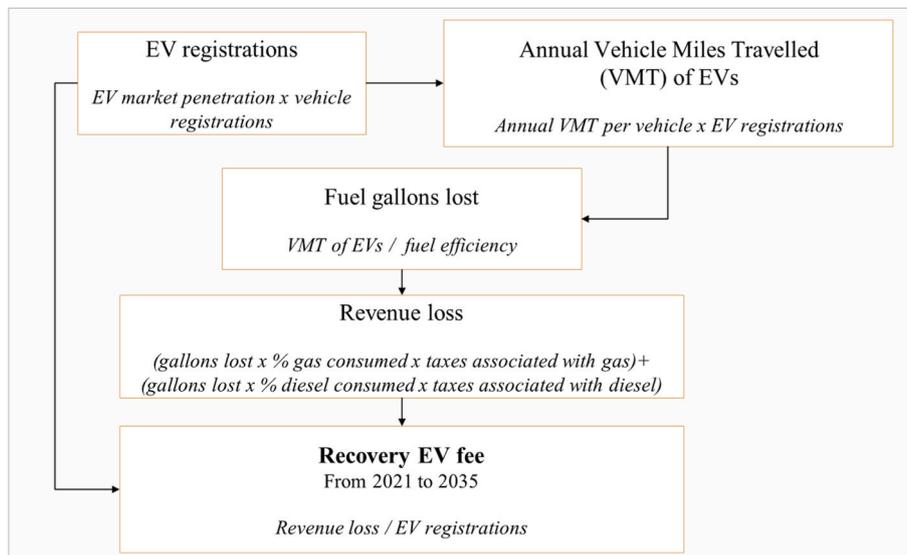
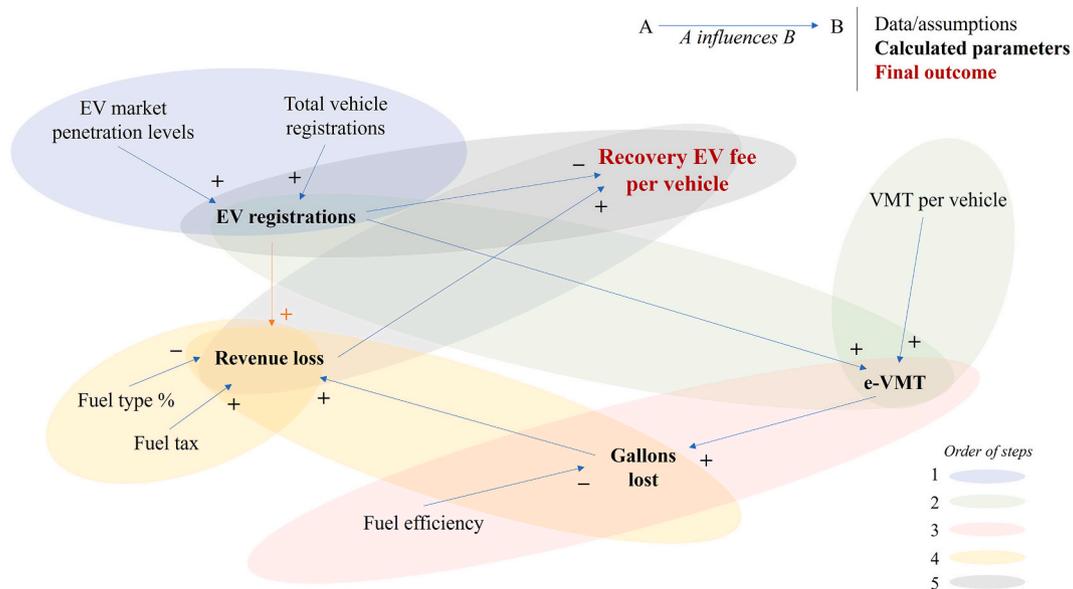**Fig. 1.** Methodology used to calculate recovery EV fee.

Fig. 2. Causal loop diagram of system dynamics for calculating the recovery EV fee.

levels and the total vehicle registrations. As the EVMP rate or vehicle registration increase, EV registrations increase as indicated by the positive sign of the specific arrows. When EV registrations increase, the VMT of EVs (e-VMT) increase and the gallons lost also increase. As the gallons lost increase, revenue loss increases. Revenue loss is also influenced by the forces of fuel tax and the percentage of vehicles that belong to each fuel type (diesel or gasoline). As the revenue loss increases, the recovery EV fee per vehicle also increases to cover this loss. It is expected that as EV registrations increase, revenue loss is distributed to more vehicles and thus, the recovery EV fee decreases. It is also expected that as revenue loss increases, the recovery EV fee increases. Due to the dynamics of the system and the way the recovery EV fee is calculated , the ratio of revenue loss to EV registrations always stays the same, even at different levels of EVMP.

4. Case study and data

A case study was developed to demonstrate the study methodology

presented in Section 3 of this paper. The case study is associated with the state of Indiana. The methodology can be applied to case studies of other states. Indiana's EV market share is relatively low compared to the average EV share in the U.S. and other states (Alliance of Automobile Innovation, 2022). As inferred in the Infrastructure Investment and Jobs Act (2021), planning for the widespread adoption of EVs is critical for effective long-term management of transportation systems. In the state of Indiana, this is a key component of the state's strategy to increase its efforts to meet current and future emissions reduction targets and climate change goals (INDOT, 2019). In Indiana, the largest portion of the state revenues consists of motor fuel taxes (57%) that are used to fund state and local transportation systems (Cambridge Systematics, Inc. et al., 2015). According to data on state motor fuel taxes (EIA, 2022a), Indiana is currently ranked 10th in a decreasing order from states with high state tax rates on gasoline to states with low tax rates on gasoline. Additionally, Indiana's (state) tax rate on gasoline is close to the national average value (EIA, 2022b). In terms of the state tax on diesel, Indiana has the second highest tax rate, exceeding the national average

value (EIA, 2022a; 2022b). Consistent with its nickname as the cross-roads for the nation's transportation systems (Cambridge Systematics, Inc. et al., 2018), Indiana possesses infrastructure that plays a key role in national and international commerce. Therefore, the state consistently seeks to ensure that its highway systems provide adequate capacity, improved road quality, and increased connectivity throughout the state for the benefit of state, regional, and international traffic, particularly, trucks. This can be done when investment amounts are adequate. Therefore, the state has a stake in identifying any threats (such as vehicle electrification) to its revenue stream.

The following paragraphs discuss the data sources and forecasts for each data type used.

4.1. Vehicle miles travelled (VMT)

Data on historical average VMT per vehicle for each vehicle class were obtained from the Highway Statistics Series, for the 2010–2019 period (FHWA, 2021a). Trend analysis was used to make projections to 2035. It was observed that VMT per vehicle for all vehicle classes except automobiles has decreased over time; this was considered rather unrealistic and impractical. Therefore, the average (or flat) line was chosen for forecasting the future VMT per vehicle, for light-duty trucks, motorcycles, buses, single-unit trucks, and combination trucks. It may be worthwhile to note that the COVID-19 pandemic has caused various social and economic changes that could change the VMT prediction in the future. For this study, the impact of COVID-19 was not taken into account because doing so would produce outlying data. Table A1 in Appendix shows the VMT per vehicle for each vehicle class, from 2021 to 2035.

4.2. Fuel taxes

The estimation of the highway fuel tax revenue was based on the following types of taxes: sales tax on gasoline/gasoline use tax, gasoline excise tax, special fuel (diesel) tax and motor carrier fuel use tax. To calculate the sales tax on gasoline, the gasoline price was multiplied by 7% (Agbelie et al., 2010). The Energy Information Administration (EIA) State Energy Data System (EIA, 2021b) was accessed to obtain the average annual gasoline prices for the transportation sector in Indiana from 1970 to 2018 in dollars per million British thermal units ($/MMBtu). These prices were converted to approximate dollars per gallon ($/gallon) using the heat contents provided in the petroleum consumption and fuel ethanol table of EIA (EIA, 2021a). Historical data on the rates of gasoline and special fuel (including diesel) were collected from the Indiana Legislative Services Agency (2018) that contained state fuel tax rates for some years between 1943 and 2018. Additionally, according to the Indiana Transportation funding chart for the fiscal year 2021 (INDOT Econometrics and Forecasting Division, personal communication, June 2021), the gasoline excise tax is 31 cents/gallon and the special fuel tax is 50 cents/gallon. In the years subsequent to the study, the state increased the gasoline tax to 33 cents/gallon and the special fuel tax to 55 cents/gallon (Indiana Department of Revenue, 2022a). Note that these rates refer to state taxes; federal taxes on gasoline or special fuel were not considered (the federal tax on gasoline and diesel fuel are 18.40 cents/gallon and 24.4 cents/gallon, respectively (EIA, 2022b). Additionally, diesel prices were not used in the revenue calculation, since, as of July 1, 2017, the sale of special fuel is exempt from the 7% gross retail tax (Indiana Department of Revenue, 2022b). Trend analysis was used to forecast gasoline prices, gasoline and diesel fuel taxes. The motor carrier fuel use tax (tax on fuel consumed by trucks in Indiana but purchased in other states) is taxed at the same rate as the special fuel tax since 1985 (Indiana Legislative Services Agency, 2018). Table A2 of Appendix shows the gasoline prices, gasoline and diesel fuel taxes from 2021 to 2035.

4.3. Existing EV fee

Data on existing EV supplemental "registration" fees were obtained to compare existing EV fees with the recovery EV fee. In Indiana, EV owners pay a supplemental fee of $150 (Bureau of Motor Vehicles, 2022; Indiana Legislative Services Agency, 2018). The fee is termed "EV registration" fee by the Bureau of Motor Vehicles (BMV), a term that could be described as a misnomer because it is intended to cover not only the registration but also the road use by EVs. It was assumed that this EV supplemental "registration" fee increases with a rate identical to the inflation rate. Therefore, historical data on the inflation rate (12-month percent change in CPI) from 2010 to 2020 were collected from the U.S. Bureau of Labor Statistics (n.d.) and an average (flat line) was used to project the fee level to 2035 (Knoema, n.d.). Figure A.1 of Appendix presents the existing/projected EV supplemental "registration" fees.

4.4. Vehicle registrations

EV registrations are estimated as a percentage of total vehicle registrations. Therefore, data on the latter were needed. This data were obtained from the Highway Statistics reports for 2010–2019 (FHWA, 2021a). More specifically, this source included data for automobiles, buses, motorcycles and a general vehicle category referred to as "trucks". To disaggregate the truck registrations to the categories of light-duty, single-unit and combination trucks, the following steps were taken: (i) distribution factors were applied using information from Agbelie et al. (2010) to first disaggregate truck registrations into different truck weight classes and (ii) the registrations for the different truck weight classes were grouped into light-duty, single-unit and combination trucks (Agbelie et al., 2010; Alternative Fuels Data Center, n.d.; FHWA, 2021b). Trend analysis was used to forecast the number of vehicle registrations up to 2035 (Table A3).

4.5. Fuel efficiency

Historical data for the 2010–2019 period related to the fuel efficiency (miles per gallon) of automobiles ("Light-duty short wheelbase"), light trucks ("Light-duty long wheelbase"), and single-unit trucks ("heavy-duty trucks") were obtained from EIA (EIA, 2021c). To estimate the fuel efficiency for combination trucks, 2017 data from Alternative Fuels Data Center (2017) were used. The ratio of the reported fuel efficiency of single-unit trucks to the fuel efficiency of combination trucks in 2017 was estimated. This ratio was used to determine the fuel efficiency of combination trucks from 2010 to 2019 based on the EIA data for single-unit trucks. For motorcycles and buses, historical data for the same period were obtained from the VMT table of Highway Statistics (FHWA, 2021a) that also reported the average miles travelled per gallon of fuel consumed. Trend analysis was used to make projections to 2035. The results are presented in Table A.4 of the Appendix of this paper.

4.6. Fuel consumption percentages

Data on the fuel-type split for each vehicle type were obtained from Agbelie et al. (2010). The fuel consumed by automobiles and motorcycles was considered to be 100% gasoline. 95% and 5% of light and single-unit trucks were considered to use gasoline and special fuel, respectively. The amount of fuel consumed by buses and combination trucks was considered 100% from special fuel. These percentages were assumed to remain the same during the analysis period. The motor carrier fuel use tax is imposed on fuel used in the state but bought at other states. This tax is also multiplied by a percentage of the (special fuel) gallons consumed by motor carriers (combination trucks). This percentage was obtained for 2021–2035 from Agbelie et al. (2010).
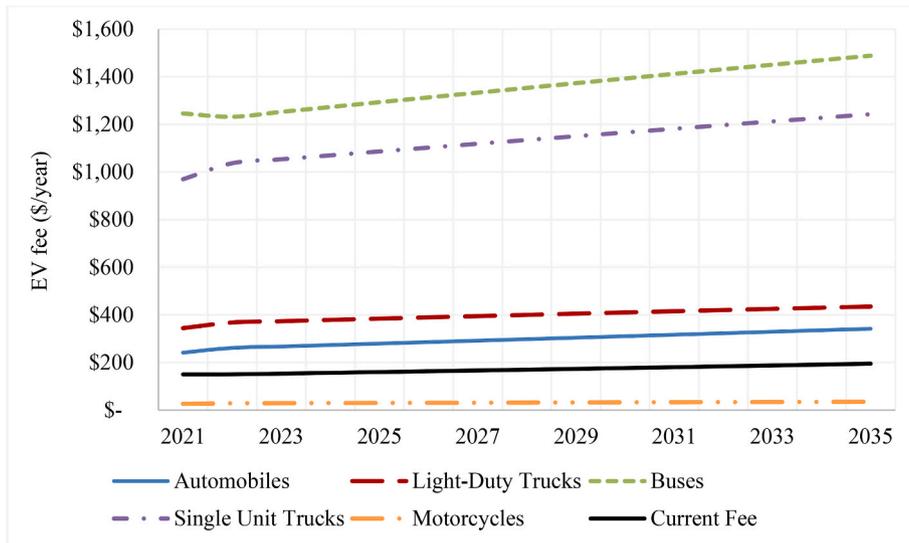
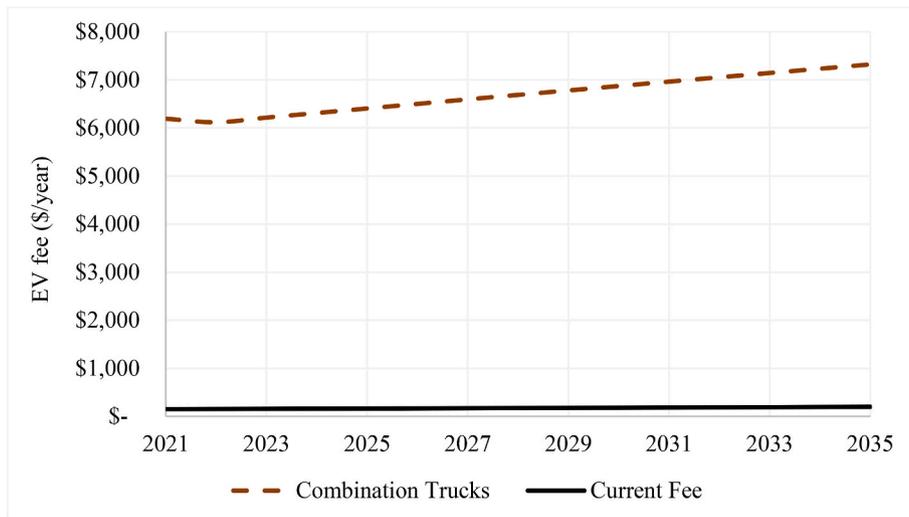**Fig. 3.** Recovery EV fee for automobiles, motorcycles, light-duty trucks, single-unit trucks and buses.

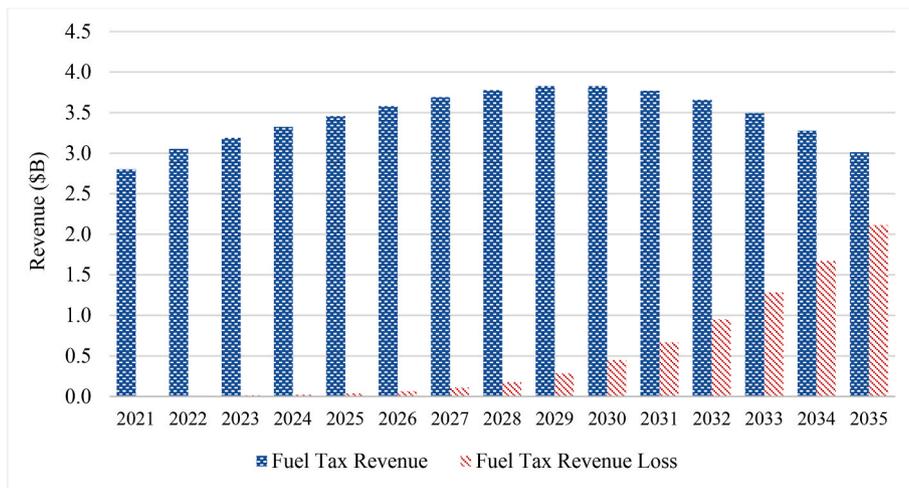**Fig. 4.** Recovery EV fee for combination trucks.

Fig. 5. Projections of total fuel tax revenue and revenue loss in Indiana (for the most likely EVMP scenario).

4.7. EV market penetration levels (EVMP levels)

The EVMP was defined as the number of EV registrations relative to the total number of vehicle registrations. EVMP levels were considered equal across the vehicle classes within each of the main vehicle groups (light-, medium- and heavy-duty vehicles). Different scenarios for the EVMP levels were examined in the study. However, due to space limitations, this paper presents only the most likely scenario and an aggressive scenario; these are described in subsequent paragraphs. As mentioned in Section 3 of this paper, S-curves were created to project the EVMP. 2018 EVMP data were found based on FHWA (2021a) (total vehicle registrations) and Alternative Fuels Data Center (2018) (EV registrations) and each data point constituted a single observation on the S-curve. The data from the Alternative Fuels Data Center were for light-duty vehicles in Indiana (approximately 0.05% EVMP level in 2018). For medium- and heavy-duty vehicles, a 0% EVMP level was assumed for 2018.

Regarding future projections, a literature review was conducted to identify the combination of parameters (EVMP levels and year at which these market penetration levels will occur) that would first form a baseline or most likely scenario for the future. It was found that rather limited data exist on Indiana's EV market projections. Therefore, national values were adopted in certain cases. With regard to projection periods, national studies often use a target year of 2030 for achieving various goals associated with alternative fuel vehicles. For example, in the U.S., it has been targeted that half of all new vehicles sold in the U.S. in 2030 should be zero-emissions vehicles (The White House, Office of the Press Secretary, 2021). Major automakers have endorsed this target and are planning for an EV share of 50% for all cars manufactured by 2030 (The White House, Office of the Press Secretary, 2021). In the case of Indiana, information on market penetration rates of light-duty vehicles in 2030 were obtained from M.J. Bradley & Associates (2018). According to their "moderate" scenario for EVMP in Indiana, a 5% market penetration level seems more likely. This projection was validated though direct communications with INDOT personnel.

With regard to medium- and heavy-duty vehicles, there are even fewer publicly available sources to date regarding their future market shares. Most projections are presented mainly in the form of goals for electrification in the U.S. For example, a memorandum of understanding has been signed by a diverse mix of states that calls for 30% of new medium- and heavy-duty vehicles to be zero-emission by 2030 (NES-CAUM, 2021). In addition to these goals, the results of a stated preference survey of 200 medium-and heavy-duty fleet managers were used to inform this study. More specifically, this survey was conducted in the U. S. during May 2021 (Konstantinou, 2022). Descriptive statistics of the survey data included the percentages of the medium- and heavy-duty fleet that are targeted for electric propulsion by 2030. The survey produced a pessimistic, average and optimistic scenario for the future adoption of electric medium- and heavy-duty vehicles according to the respondents. The pessimistic scenario projected approximately 30% electric medium-duty and 30% heavy-duty vehicle market penetration level in 2030 and this scenario was chosen as the most likely scenario. This is because Indiana is not considered an "early adopter" of EV technology compared to other states (Alliance of Automobile Innovation, 2022; M.J. Bradley & Associates, 2018).

Therefore, assuming equal EVMP levels across the vehicle classes within each vehicle group, the most likely scenario is based on: 5% EVMP level for light-duty vehicles, 30% EVMP vehicles for medium-duty vehicles and 30% EVMP level for heavy-duty vehicles in 2030. Additionally, an aggressive scenario (100% EVMP) was considered and assumed to commence in 2030 for each vehicle class. This scenario was formed mainly to set an upper bound but it may be very unlikely to be achieved unless catalyzed by aggressive government policy (M.J. Bradley & Associates, 2018). The 2018 EVMP data, the projections for 2030 as well as peak market shares were used to inform the S-curves. The peak market shares (refer to equation (1), Section 3) were assumed to be 90% and 95% for light-duty and medium-or heavy-duty vehicles, respectively, for the most likely scenario. For the aggressive scenario, the peak market shares were assumed 100%.

4.8. Alternative funding mechanisms

This study also estimated alternative ways to implement the recovery EV fee and help mitigate the decline in revenue generation. These options included VMT fees and taxes on electricity. To calculate the VMT fee, the average VMT per vehicle was used which was described earlier (see VMT discussion in Section 4). To calculate the EV consumption per vehicle class (total kwh), it is needed to estimate the tax on electricity. This requires data on the VMT and efficiency or energy consumption rate (kwh/mile) of each vehicle class. It may be noted that there still exists rather limited information and uncertainty regarding EV efficiency (kwh/mile) for heavier vehicles. Therefore, to provide an estimation of this data, average or indicative values from publicly available data sources were used in this study. Table 1 presents the data sources used for all vehicle classes. It was assumed that the EV energy consumption rate decreases by 2% annually due to advancement in EV technology (Muratori et al., 2021).
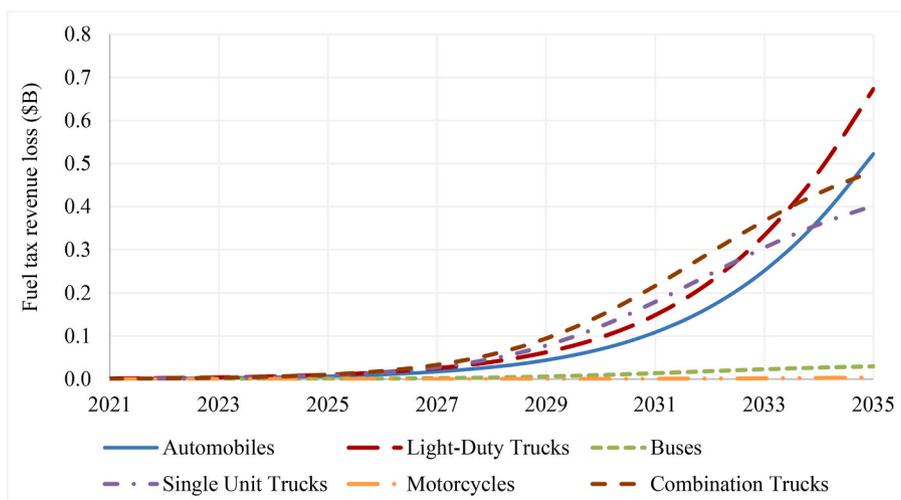
Fig. 6. Projections of revenue loss by vehicle class in Indiana (for the most likely EVMP scenario).
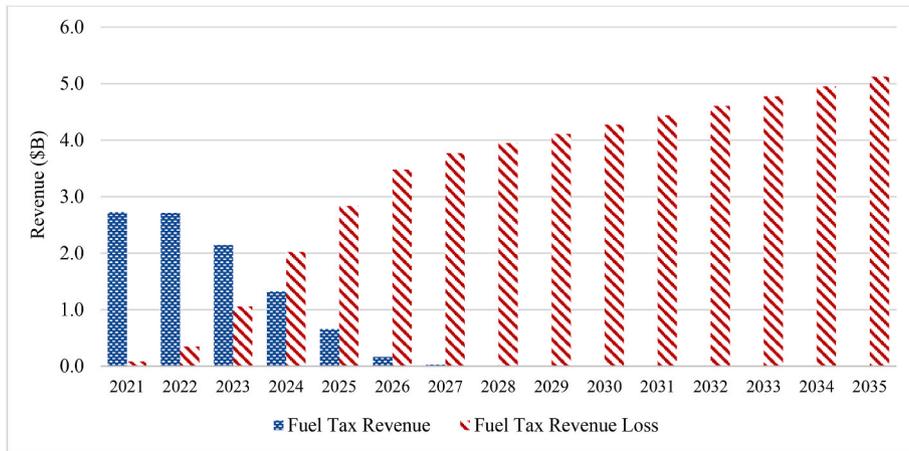
Fig. 7. Projections of total fuel tax revenue and revenue loss in Indiana (for the aggressive EVMP scenario).
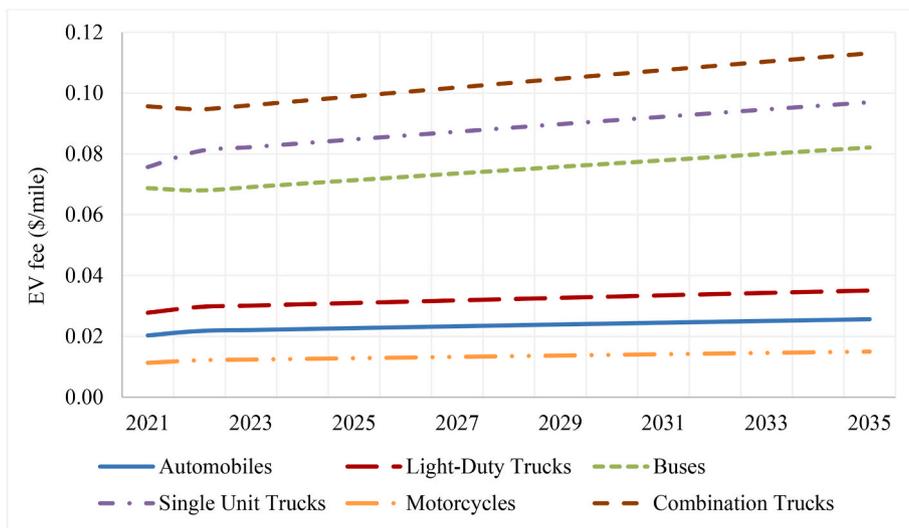

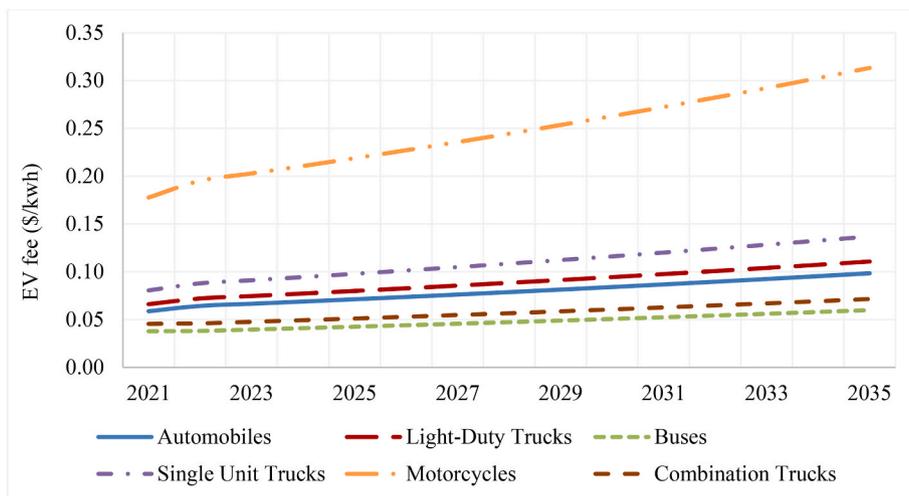**Fig. 8.** Projections of the recovery EV fee converted to a VMT fee in $/mile.

Fig. 9. Projections of the recovery EV fee converted to a pay-as-you-charge fee in $/kwh

5. Results

This section contains the findings for the recovery EV fee and the impact on revenue, assuming continuation of existing taxation structures. First, the recovery EV fee, calculated as the ratio of revenue loss to EV registrations, stays constant for different EVMP levels (also refer to Section 3). Fig. 3 presents the annual recovery EV fee from 2021 to 2035 for each automobile, motorcycle, bus, light-duty truck and single-unit truck as well as Indiana's existing (current) annual EV fee, for comparison. Fig. 4 presents the annual recovery EV fee for each combination truck along with the existing EV fee in Indiana from 2021 to 2035.

The figures show the recovery EV fee in dollars per year that should be charged annually to each vehicle for each vehicle class to recover the fuel tax revenue loss. Fuel tax revenue loss will keep increasing over the years as the EVMP increases; therefore, the recovery EV fee follows the same trend. As expected, the existing annual EV fee is significantly lower compared with the proposed EV fee (the recovery EV fee), except for the vehicle class of motorcycles. To maintain the same tax revenue per vehicle, annual fees ranging from $241 (in 2021) to $342 (in 2035) for automobiles, $344 to $435 for light-duty trucks, $1246 to $1488 for buses, $969 to $1243 for single-unit trucks, $6192 to $7321 for combination trucks and $26 to $35 for motorcycles would be needed over the analysis period. It can be observed that the recovery EV fee is high for heavier vehicles such as buses, single-unit trucks and combination trucks. This high amount can be considered appropriate because each heavier vehicle pays additional taxes and contributes more to the fuel tax revenue due to its vehicle class characteristics. Hence, to recover the revenue that is lost, a higher fee is necessary. Furthermore, this fee is an annual, direct, or one-time fee. The amount of money of this fee can be considered the same as the total amount that would be paid for fuel taxes for all the times these vehicles purchase fuel throughout the year. It is also important to note that the recovery EV fee for all EV classes is intended to cover both registration and road use and therefore, it is much higher than the registration fee of a traditional-fuel vehicle.

The impact of EV adoption on highway revenue was also estimated based on the EVMP scenarios described in Section 4 (most likely scenario: 5% for light-duty vehicles and 30% for medium- or heavy-duty vehicles in 2030; aggressive scenario: 100% EVMP for each vehicle class in 2030). Fig. 5 presents the state fuel tax revenue and revenue loss for all vehicle classes combined, from 2021 to 2035, for the most likely scenario of EVMP. The fuel tax revenue (blue bars) refers to the revenue that would be generated from gasoline or diesel vehicles given the most likely EVMP levels. The graph also presents the fuel tax revenue loss due to EVs (red bars). For example, in 2035, the total fuel tax revenue will be approximately $3B due to the revenue loss associated with EVs ($2.1B). If there were no revenue loss, the total fuel tax revenue would be approximately $5.1B. The average annual fuel tax revenue loss is approximately $523M ($646.5 per vehicle on average or $0.047 per VMT on average). The average annual growth rate of the revenue loss is approximately 57%. The fuel tax revenue decreases by approximately 21% from 2030 to 2035. Fig. 6 presents the fuel tax revenue loss by

vehicle class. The average annual fuel tax revenue loss per vehicle for each vehicle class is around: $329 for automobiles, $425 for light-duty trucks, $1438 for buses, $1204 for single-unit trucks, $7096 for combination trucks and $34 for motorcycles.

With regard to the aggressive EVMP scenario, the cumulative revenue loss from 2021 to 2035 is approximately $50B (Fig. 7), which is roughly $42B higher than the cumulative revenue loss of the most likely scenario. The average annual state fuel tax revenue loss is approximately $3.3B ($428 per vehicle on average or $0.033 per VMT on average). As expected, the total fuel tax revenue in this scenario would be zero from 2030 to 2035 due to the 100% EVMP. In this scenario, the average annual fuel tax revenue loss per vehicle for each vehicle class was found to be around: $308 for automobiles, $408 for light-duty trucks, $1399 for buses, $1173 for single-unit trucks, $6913 for combination trucks and $32 for motorcycles.

6. Discussion

As shown in Section 5 of this paper, it is evident that in Indiana, EV adoption will have profound impacts on fuel tax revenue. Imposing additional annual fees for EVs to recover the revenue loss can be adopted as a potential key initiative towards the sustainability of transportation revenue generation. On the other hand, such fees, notwithstanding the good intentions behind their administration, could negatively impact EVMP and consequently jeopardize the agency's emissions goals. In addition, the proposed recovery EV fees could engender public opposition due to their high levels, particularly in the case of heavy vehicle classes. Therefore, alternative ways to implement the recovery EV fee could be considered by the implementing agency to ensure sufficient revenue without jeopardizing EV adoption or public acceptance. A mix of alternative policy options to generate transportation revenues may include annual/monthly/quarterly EV fees, taxes on electricity or mileage-based fees implemented in a pay-as-you-charge manner similar to the case for traditional gasoline fuel. In the context of fees and taxes, the estimated recovery EV fee can be converted to a tax on electricity when charging an EV, measured in $/kwh, or to a user fee based on the miles driven by the vehicle, measured in $/mile.

To calculate the appropriate VMT fee to charge road users, the recovery EV fee was divided by the average VMT per vehicle (refer to Section 4 for the data sources). The recovery EV fee was also divided by the total EV consumption (refer to Section 4), resulting in a value that could be referred to as tax on electricity or "pay-as-you-charge" fee. Figs. 8 and 9 present the results regarding the VMT and pay-as-you-charge fees per vehicle class and per year to break even the fuel tax revenue loss. The calculated pay-as-you-charge fee represents the additional amount that should be charged on electricity consumed by EVs in the state to avoid the potential decrease in revenue due to EV adoption.

As it can be seen, combination trucks, single-unit trucks and buses have higher VMT fees. Motorcycles, single-unit trucks and light-duty trucks have a higher fee on a per kwh basis (compared to other vehicle classes). This shows that heavy vehicles may pay more on a per mile basis, but this is not the case with the pay-as-you-charge fee. Hence, the trend (regarding which vehicle class will pay more or less) is not consistent across the alternative mechanisms nor is it always a reflection of vehicle weight trends, which indicates that a combination of alternative mechanisms could be applied. This combination may depend on different factors such as EV market share or vehicle class characteristics (e.g., weight) or other policy or operational criteria. In the case where the charges are based on electricity consumption, then, similar to the revenue "problem" of increased fuel efficiency over time due to technology or spurred by legislation, EV efficiency values are expected to increase in the future, and less charge will be needed to travel each mile, reducing revenues from EVs. If that happens, the same revenue gap that has bedeviled gasoline fuel revenues, will also be experienced for EVs. The gap could be decreased by raising the electricity price; however, this

Table 1
Data for EV efficiency.

Vehicle class	Value (kwh/mile)	Data source
Automobiles	0.346	Average of eleven latest models from EPA (2021)
Light-duty trucks	0.421	Average of three Tesla Cybertruck models from Electric Vehicle Database (n.d.)
Buses	1.820	Number reported by Johnson et al. (2020)
Single-unit trucks	0.940	Average of three models from CARB (2018) and Smith et al. (2019)
Combination trucks	2.100	Average of six models from CARB (2018) and Smith et al. (2019)
Motorcycles	0.064	Number reported by Huang et al. (2018)

Table 2
Alternative mechanisms to implement the recovery EV fee (including the annual EV fee).

	Annual EV fee	EV fee broken into periodic payments	Pay-as-you-charge fee	VMT fee
General description	The total amount of EV recovery fee is paid once a year.	The amount of EV recovery fee is paid periodically (e.g., monthly or quarterly).	The EV recovery fee is converted to a tax on electricity when charging an EV, measured in $/kwh.	The EV recovery fee is converted to a use fee on the mileage driven by the vehicle, measured in $/mile.
Advantages	Fees are associated with vehicle ownership and thus, constitute a reliable source of revenue compared to use-based taxes (given that vehicle ownership will not significantly decline). This system is in line with the existing registration funding system and would require less education, public outreach efforts, and would be lower in cost to implement.	Costs are spread out over time, alleviating the financial impact of one-time registration fees. Fees are associated with vehicle ownership and thus, are more reliable sources of revenue.	Costs are spread out over time. Fees are similar to the pay-at-the-pump nature of existing fuel taxes, facilitating their adoption by the public and implementation by the agencies.	Costs are spread out over time. Fees can be easily adjusted based on different parameters (e.g., road type, vehicle weight, time of day) to account for the actual cost caused to the transportation network. This mechanism may lead to more strategic/targeted investments in transportation infrastructure, since it can provide accurate information about which roads have high EV traffic.
Disadvantages	Fees are too high to be paid upfront. Fees may hinder the promotion of EV adoption, especially from heavier vehicle classes that have higher costs. Fees do not consider mileage or usage. Fees may become unsustainable in a future with shared mobility.	Fees may still hinder the promotion of EV adoption if the periodic payment is still high. Fees do not consider mileage or usage. Fees may become unsustainable in a future with shared mobility. Periodically collecting fees (e.g., every month or quarter) may add administrative burden.	It may be complex to accurately measure the location and time of EV charging to estimate the fee/tax. Most charging occurs at home, and it would be difficult and costly to separate the EV electricity usage from the household usage. Fees may not be as accurate as a weight-based metric for assessing the impact of vehicles on the roads, even though heavier vehicles will generally use more kwh per mile. Imposing fees on charging infrastructure could discourage its use and purchase of EVs. There may be privacy-related concerns if energy usage/charging location data are shared (with power companies or third-party data aggregators). There may be concerns regarding experiencing the same revenue gap, since EV efficiency is expected to improve (less charge will be needed to travel each mile).	There may be privacy-related concerns due to the fact that the distances travelled are monitored. Administrative burden can be high since tracking technology, account management and transaction charges may be needed. The imposition of this fee is associated with deadweight loss, since users may pay extra for the technology/equipment needed and this revenue is not distributed to the government.
Policy considerations	Additional design is needed to account for the amount of driving and avoid potential disparity between EV miles driven and the amount paid for road usage. EV users with low mileage may be charged more per mile than EV users with higher mileage. Increased fees over time may work in opposition to purchase incentives for EVs given by state and federal governments. Fees can be combined with mileage-based or pay-as-you charge fees.	The EV fee broken into periodic payments may apply only to the case of vehicle classes whose annual EV fee is significantly high. The threshold for considering an EV fee high should be investigated. Their implementation may require proper technology to make fee collection easier and without many resources (e.g., online). Additional design is also needed to account for the amount of driving and avoid potential disparity between EV miles driven and the amount paid for road usage.	Their implementation may require both on-vehicle technology (e.g., vehicle telematics) and submetering or smart chargers to measure the electricity consumption coming from EVs. Any approach should be designed properly to protect the privacy of drivers. Fees can be indexed for inflation to maintain the purchasing power of revenue generated by the fees. Utilities should build new tariff structures to reward certain charging behaviors (e.g., off-peak charging) to decrease user cost and thus, increase adoption. A connection between utilities, the state departments of transportation and regulators should be developed (which is similar to the motor fuel industry) to effectively remit payments to revenue collection agencies, especially for the case of home charging.	Proper technology is needed (e.g., VMT tracking dongles) to facilitate communication between the mileage-reporting device and the EV and thus, fee collection. The cost of such equipment could be subsidized fully or partially. This mechanism may need specific design to encourage fuel efficiency. From a user perspective, EVs could be made to have lower VMT fees. Any EV fee should be adjusted appropriately to generate enough funding for transportation. The combination of this mechanism with weight-based fees would create a fairer rate structure. Utilities can collect a portion of the fee to cover administrative costs. Their implementation may require mutli-state implementation and agreements.

will be difficult because transportation is not the only source of electricity and raising electricity prices to close the transportation revenue gap will affect the residential and industrial markets unduly.

Table 2 describes the alternative policy options to generate transportation revenues, including EV fees, taxes on electricity or mileage-based fees. The information shown in the table are based on the study findings and highway funding literature (refer to Section 2) and can serve as a useful resource for policymakers who will be seeking to evaluate alternative ways to close the gap between transportation infrastructure investment needs and available resources in the vehicle electrification era. From the information presented in Table 2, it is expected that implementing the recovery EV fee as a flat fee for EVs may become unsustainable in a future of shared mobility, and may generate opposition from the public and road users, particularly, commercial vehicles. Furthermore, such flat fees do not consider mileage or usage. As a result, EV users with low mileage, for instance, may be charged more per mile than EV users with higher mileage or there may be created an incentive for increased driving. Thus, additional design is needed to scale these fees to account for the amount of driving and avoid potential disparity between EV miles driven and the amount paid for road usage. A VMT ($/mile) or pay-as-you-charge ($/kwh) fee may be more appropriate and equitable. In particular, a VMT fee could be easily adjusted or combined with weight-based fees to account for the actual cost caused to the transportation network, in which case the transportation agencies will need to develop appropriate technology solutions to address privacy-related concerns. Additionally, from a user perspective, EVs could be made to enjoy a discount on their VMT fees because they offer other societal benefits including emission reduction and energy security. However, any such discount will need to be designed appropriately in order not to threaten the adequacy of transportation funding. A pay-as-you-charge fee ($/kwh) is similar to the pay-at-the pump nature of existing fuel taxes, and such familiarity could encourage acceptance by the public. Nevertheless, it would be a rather complicated effort to separate EV electricity usage from household usage (for home charging) versus that from public charging facilities. Therefore, partnerships between utilities and transportation agencies will need to be developed in order to effectively remit payments associated with EV charging at home. It is also worth noting that, in the case where charges are based on electricity consumption or VMT, there exist strategies to protect revenue from uncertainty factors such as price jumps and falls due to unexpected events. Fees could be adjusted in the future based on a collar strategy (Shan et al., 2010) so that agencies are protected from low fees and highway users are protected from high fees.

7. Conclusions

The study sought to provide information that could enhance highway agency revenue sustainability by (i) assessing the impact of EV adoption on the state fuel tax revenue based on scenarios of EVMP levels, (ii) identifying the optimal EV fee, and (iii) examining the potential of funding mechanisms to recover the revenue loss. It was found that, in the most likely scenario (5% EVMP for light-duty vehicles and 30% EVMP for medium- and heavy-duty vehicles), the Indiana fuel tax revenue will decrease by 21% by 2035, relative to 2030. To maintain the same fuel tax revenue per vehicle, annual fees ranging from $241 (in 2021) to $342 (in 2035) for automobiles, $344 to $435 for light trucks, $1246 to $1488 for buses, $969 to $1243 for single-unit trucks, $6192 to $7321 for combination trucks, and $26 to $35 for motorcycles would be needed over the analysis period (2021–2035). The recovery EV fee was converted to a VMT ($/mile) and pay-as-you-charge ($/kwh) fee per vehicle class and per year. Potential barriers to the implementation of these options (e.g., sustainability, costs, privacy concerns) and policy aspects (e.g., implementation process, partnerships, equity considerations) were examined.

The methodology was applied using a case study of the state of Indiana, however, it can be easily replicated and applied in other states.

Additionally, this study can help transportation agencies and state legislatures better understand the impact of EVs on the highway revenue and serve as a reference to support decision making regarding preparedness for prospective EV operations in the future. This can be achieved through several ways. First, the well-documented framework of this study can be adopted by transportation agencies to inform or be part of their existing revenue model, estimating optimal EV fees. Next, the discussion of the alternative funding mechanisms can guide transportation agencies or other stakeholders involved in terms of which alternative funding mechanism to choose. As it has been discussed in this study, implementing the recovery EV fee as an annual flat fee for EVs may generate opposition from the public and road users, particularly, commercial vehicles, and such fees do not consider mileage or usage. Therefore, to offset the gasoline revenue loss, a VMT ($/mile) or pay-as-you-charge ($/kwh) fee may be more appropriate and equitable. While this paper does not advocate for a specific mechanism, it provides the necessary information or aspects to consider for the decision-making process (e.g., refer to Table 2).

Additionally, the estimations of the recovery EV fee, the VMT fee and pay-as-you-charge fee (refer to Sections 5 and 6) can be used as a basis for survey public opinion to capture users' perspectives and willingness-to-pay and to estimate appropriate fee rates and structures, such that sufficient revenue is raised and public acceptance is achieved. Depending on the users' perspectives, the fees of this study can be then adjusted and used in pilot programs. Extensive public outreach and education should also be undertaken to inform users about the overall long-term cost savings associated with EV use. This can help earn public support. Further, the best combination of alternative policy options can be identified through pilot programs. This study highlights an opportunity to prepare transportation agencies for participating in pilot programs on alternative funding mechanisms so that EVs can contribute their fair share to roadway development and preservation. As described in Section 2, states have begun to explore either the potential of alternative funding mechanisms to replace fuel taxes or the impact of EV adoption. These efforts, including the current study, are conducted at a state level and inform the initiatives at regional or federal levels.

This study has certain limitations that can constitute ideas for future research and methodological refinement. The analysis focused on five main vehicle classes and on estimating the impacts of battery EVs. Future research could expand the analysis by not only disaggregating the results by weight class, which would be particularly revealing from the trucks' perspective, but also considering other alternative fuel vehicles. Another avenue for future research can be to account for variations in VMT based on different factors, such as age cohort within each vehicle category, drivetrain type, demographic/household characteristics, geographic distribution, land-use and others. Furthermore, the scope of this paper focuses on fuel tax revenue or fuel taxes. Nevertheless, there are additional revenue sources associated with the vehicle operation and maintenance expenditures. The revenue from these sources may be different between traditional vehicles and EVs and may need to be considered in future work. Future work can also focus on identifying ways to "correct" existing taxes to account for the true cost of driving or costs that are not currently incorporated into the market price, including costs on society such as emission damages, and other externalities, such as military and related political costs of keeping oil prices low.

Moreover, this analysis calculated the optimal EV fee to recover the fuel tax revenue loss without explicitly accounting for the equity of funding mechanisms across the different vehicle classes. Future research can work on developing effective metrics to capture this aspect and ascertain an equitable fee structure (e.g., Burris et al., 2015). The research framework used to estimate the impact of EV adoption on fuel tax revenue and to estimate the optimal EV fee can also be expanded and consider how transportation revenue sources can align with available funds and broader state emission and electrification goals. Additionally, the research framework can be modified to consider federal taxes in

addition to state taxes. In this case, the estimated recovery EV fees would be higher, depending on whether a state is a donor state or not. Moreover, the actual implementation of the options proposed will need in-depth studies to examine both the user perspective and the necessary procedures for the implementation of EV fees, such as their collection process, appropriate technologies, administrative costs and more. For instance, a study of urban and rural areas can be conducted (e.g., public opinion survey, pilot projects) in the future to answer any concerns about road usage charging policy. This paper is based on user-focused pricing concepts. Future work can explore facility-focused pricing such as toll roads and potential complexities generated by double taxation due to paying both motor fuel taxes/fees and tolls. Lastly, the analysis did not consider unexpected events affecting prices/taxes and the results are contingent on the best available information for the parameters involved. As more information impacting the assumptions becomes available (e.g., efficiency of EVs), it will be easy to modify the assumptions and replicate the analysis in the future.

CRediT authorship contribution statement

Theodora Konstantinou: Conceptualization, Investigation, and, literature review, Data curation, Formal analysis, Methodology, Visualization, Writing – original draft, Writing – review & editing. **Samuel Labi:** Conceptualization, Funding acquisition, Supervision, Methodology, data collection, Writing – review & editing. **Konstantina Gkritza:** Conceptualization, Funding acquisition, Project administration, Supervision, Writing – review & editing.

Declaration of competing interest

The authors declare that they have no known competing financial interests or personal relationships that could have appeared to influence the work reported in this paper.

Acknowledgements

APPENDIX

Table A.1
VMT (in thousands) per vehicle for each vehicle class (2021–2035) in Indiana

Year	Automobiles	Light-Duty Trucks	Buses	Single Unit Trucks	Combination Trucks	Motorcycles
2021	11.88	12.39	18.12	12.81	64.73	2.34
2022	11.99	12.39	18.12	12.81	64.73	2.34
2023	12.09	12.39	18.12	12.81	64.73	2.34
2024	12.19	12.39	18.12	12.81	64.73	2.34
2025	12.29	12.39	18.12	12.81	64.73	2.34
2026	12.40	12.39	18.12	12.81	64.73	2.34
2027	12.50	12.39	18.12	12.81	64.73	2.34
2028	12.60	12.39	18.12	12.81	64.73	2.34
2029	12.71	12.39	18.12	12.81	64.73	2.34
2030	12.81	12.39	18.12	12.81	64.73	2.34
2031	12.91	12.39	18.12	12.81	64.73	2.34
2032	13.01	12.39	18.12	12.81	64.73	2.34
2033	13.12	12.39	18.12	12.81	64.73	2.34
2034	13.22	12.39	18.12	12.81	64.73	2.34
2035	13.32	12.39	18.12	12.81	64.73	2.34

Table A.2
Fuel tax rates (2021–2035) in Indiana

Year	Gasoline Price ($/gallon)	Gasoline Fuel Tax (cents/gallon)	Special Fuel Fuel Tax (cents/gallon)	Special Fuel for MCFUT Fuel Tax (cents/gallon)
2021	2.71	31.00	50.00	50.00
2022	3.30	31.21	51.34	51.34
2023	3.37	31.35	51.65	51.65
2024	3.45	31.92	52.68	52.68
2025	3.52	32.49	53.72	53.72
2026	3.59	33.06	54.75	54.75
2027	3.67	33.63	55.78	55.78
2028	3.74	34.19	56.81	56.81
2029	3.82	34.76	57.84	57.84
2030	3.89	35.33	58.88	58.88
2031	3.96	35.90	59.91	59.91
2032	4.04	36.47	60.94	60.94

Table A.2 (*continued*)

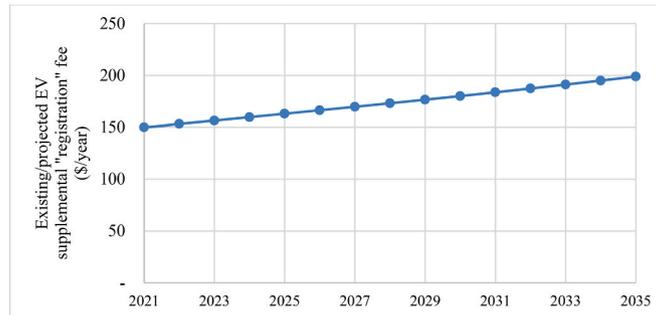| Year	Gasoline Price ($/gallon)	Gasoline Fuel Tax (cents/gallon)	Special Fuel Fuel Tax (cents/gallon)	Special Fuel for MCFUT Fuel Tax (cents/gallon)
2033	4.11	37.04	61.97	61.97
2034	4.19	37.61	63.01	63.01
2035	4.26	38.18	64.04	64.04

Fig. A.1. Existing/projected (battery) EV supplemental "registration" fees (2021–2035) in Indiana

Table A.3
Vehicle registration frequencies (in millions) per vehicle class (2021–2035) in Indiana

Year	Automobiles	Light-Duty Trucks	Buses	Single Unit Trucks	Combination Trucks	Motorcycles
2021	3.31	3.84	0.02	0.29	0.06	0.27
2022	3.44	3.94	0.02	0.29	0.06	0.28
2023	3.57	4.04	0.02	0.30	0.06	0.29
2024	3.70	4.14	0.02	0.31	0.06	0.30
2025	3.84	4.23	0.02	0.31	0.07	0.30
2026	3.97	4.33	0.02	0.32	0.07	0.31
2027	4.10	4.43	0.02	0.33	0.07	0.32
2028	4.23	4.53	0.02	0.34	0.07	0.33
2029	4.36	4.62	0.02	0.34	0.07	0.33
2030	4.49	4.72	0.02	0.35	0.07	0.34
2031	4.62	4.82	0.02	0.36	0.07	0.35
2032	4.75	4.91	0.02	0.36	0.07	0.35
2033	4.88	5.01	0.02	0.37	0.08	0.36
2034	5.01	5.11	0.02	0.38	0.08	0.37
2035	5.14	5.21	0.02	0.39	0.08	0.38

Table A.4
Fuel efficiency (in miles per gallon) per vehicle class (2021–2035) in Indiana

Year	Automobiles	Light-Duty Trucks	Buses	Single Unit Trucks	Combination Trucks	Motorcycles
2021	24.59	17.99	7.42	6.61	5.36	44.22
2022	24.73	18.09	7.45	6.63	5.39	44.30
2023	24.86	18.18	7.47	6.66	5.41	44.37
2024	25.00	18.28	7.50	6.69	5.43	44.45
2025	25.14	18.37	7.53	6.72	5.45	44.53
2026	25.28	18.47	7.55	6.74	5.48	44.61
2027	25.41	18.56	7.58	6.77	5.50	44.69
2028	25.55	18.66	7.61	6.80	5.52	44.77
2029	25.69	18.75	7.64	6.83	5.54	44.84
2030	25.82	18.85	7.66	6.85	5.56	44.92
2031	25.96	18.94	7.69	6.88	5.59	45.00
2032	26.10	19.03	7.72	6.91	5.61	45.08
2033	26.23	19.13	7.74	6.93	5.63	45.16
2034	26.37	19.22	7.77	6.96	5.65	45.23
2035	26.51	19.32	7.80	6.99	5.67	45.31

References

Agbelie, B., Bai, Q., Labi, S., & Sinha, K. (2010). Forecasting of highway revenues under various options (FHWA/IN/JTRP-2010/03). *Joint Transportation Research Program,* *Indiana Department of Transportation and Purdue University.* https://doi.org/10.5703/1288284314268

Alliance of Automobile Innovation. (2022). Advanced technology vehicle sales dashboard data. *Data compiled by the Alliance for Automotive Innovation using*

information provided by IHS Markit (2011–2018, Nov 2019-2021) and Hedges & Co. (Jan 2019–Oct 2019). Retrieved March 20, 2022 https://www.autosinnovate.org/initiatives/energy-and-environment/electric-drive.

Alternative Fuels Data Center. (2018). Maps and data. *Electric Vehicle Registrations by State*. https://afdc.energy.gov/data/10962.

Alternative Fuels Data Center. Maps and data—vehicle weight classes & categories. https://afdc.energy.gov/data/10380.

Alternative Fuels Data Center. (2017). Maps and data. Average fuel Economy by major vehicle category. https://afdc.energy.gov/data/.

American Planning Association. (2010). Rebuilding America: APA national infrastructure investment task force report. https://mostcenter.umd.edu/rebuilding-america-apa-national-infrastructure-investment-task-force-report.

ATA. (2020). Economics and industry data. American trucking associations. https://www.trucking.org/economics-and-industry-data.

Berg, J. T. (1990). Taxation and revenue policies for future federal highway programs. *Transportation Research Part A: General, 24*(4), 251–264. https://doi.org/10.1016/0191-2607(90)90002-N

Bräunl, T., Harries, D., McHenry, M., & Wager, G. (2020). Determining the optimal electric vehicle DC-charging infrastructure for Western Australia. *Transportation Research Part D: Transport and Environment, 84*, Article 102250. https://doi.org/10.1016/j.trd.2020.102250

Brown, A. L., Fleming, K. L., & Safford, H. R. (2020). Prospects for a highly electric road transportation sector in the USA. *Current Sustainable/Renewable Energy Reports, 7*, 84–93. https://doi.org/10.1007/s40518-020-00155-3

Bureau of Motor Vehicles. (2022). Fee chart [PDF file]. https://www.in.gov/bmv/files/Fee_Chart.pdf.

Burris, M., Lee, S., Geiselbrecht, T., Baker, R., & Weatherford, B. (2015). Equity evaluation of sustainable mileage-based user fee scenarios. *Journal of the Transportation Research Forum, 54*(1). https://doi.org/10.5399/osu/jtrf.54.1.4264. Article 1.

BYD. (2020). Anheuser-busch names BYD "sustainable supplier of the year"—BYD USA. https://en.byd.com/news/anheuser-busch-names-byd-sustainable-supplier-of-the-year/.

Cambridge Systematics, Inc., D'Artagnan Consulting, LLP, & Indiana University. (2015). Study of Indiana transportation infrastructure funding mechanisms. Indiana department of transportation. https://www.in.gov/indot/3410.htm.

Cambridge Systematics, Inc., Global Logistics Development Partners, & Hanson Professional Services Inc. (2018). Indiana multimodal freight plan update 2018. *Indiana Department of Transportation.* https://www.in.gov/indot/files/Indiana%202018%20State%20Freight%20Plan.pdf.

CARB. (2018). Battery electric truck and bus energy efficiency compared to conventional diesel vehicles. https://ww2.arb.ca.gov/sites/default/files/2018-11/180124hdbevefficiency.pdf.

Chamberlin, R., Kergaye, C., & Nichol, K. (2016). Methodology to assess high efficiency vehicle trends on fuel tax revenue in Utah (No. 16–1106). Article 16–1106. In *Transportation research board 95th annual meeting.* Washington, DC, U.S.: Transportation Research Board. https://trid.trb.org/view/1392407.

Choi, D. G., Kreikebaum, F., Thomas, V. M., & Divan, D. (2013). Coordinated EV adoption: Double-digit reductions in emissions and fuel use for $40/Vehicle. *Environmental Science and Technology, 47*(18), 10703–10707. https://doi.org/10.1021/es4016926

Coussan, P., & Hicks, M. (2009). Coping with transportation funding deficits: A survey of the states. Association county commissioners of Georgia. http://www.accg.org/library/ACCG%20Transportation%20Funding%20Survey%20of%20the%20States_Fall%202009.pdf.

Daimler. (2020). Electric vehicles from Daimler Trucks & Buses prove their capabilities in customer use worldwide: More than 7 million kilometers driven. MarsMediaSite. https://media.daimler.com/marsMediaSite/en/instance/ko/Electric-vehicles-from-Daimler-Trucks-Buses-prove-their-capabilities-in-customer-use-worldwide-more-than-7-million-kilometers-driven.xhtml?oid=47398028.

Daimler. (2021). Daimler trucks north America opens order books for industry-leading all-electric freightliner eCascadia and eM2. https://daimler-trucksnorthamerica.com/PressDetail/daimler-trucks-north-america-opens-order-2021-04-06.

EIA. (2021a). Monthly energy review. Appendix A. A3: Petroleum consumption and fuel ethanol. Retrieved July 11 https://www.eia.gov/totalenergy/data/monthly/index.php.

EIA. (2021b). SEDS. Prices and expenditures. *Prices.* Retrieved July 10 https://www.eia.gov/state/seds/seds-data-complete.php?sid=US#CompleteDataFile.

EIA. (2021c). Total energy. Data. Table 1.8 motor vehicle mileage, fuel consumption, and fuel economy. *Retrieved July 11* https://www.eia.gov/totalenergy/data/browser/?tbl=T01.08.

EIA. (2022a). Federal and state motor fuel taxes. https://www.eia.gov/petroleum/marketing/monthly/xls/fueltaxes.xls.

EIA. (2022b). Frequently Asked Questions (FAQs). How much tax do we pay on a gallon of gasoline and on a gallon of diesel fuel?. https://www.eia.gov/tools/faqs/faq.php?id=10&t=5.

Electric Vehicle Database. All electric vehicles. EV Database. https://ev-database.org/.

EPA. (2021). Fuel economy. Advanced cars & fuels. All electric vehicles. https://www.fueleconomy.gov/feg/PowerSearch.do?action=noform&path=1&year1=2020&year2=2021&vtype=Electric&pageno=1&rowLimit=50.

FHWA. (2019). Table HF-10. *Funding for highways and disposition of highway-user revenues, all units of government, 2019.* https://www.fhwa.dot.gov/policyinformation/statistics/2019/hf10.cfm.

FHWA. (2021a). Highway statistics Series. Policy and governmental affairs. Office of highway policy information. *Federal Highway Administration. Retrieved May 12* https://www.fhwa.dot.gov/policyinformation/statistics.cfm.

FHWA. (2021b). Traffic monitoring guide. Appendix C. Vehicle types. https://www.fhwa.dot.gov/policyinformation/tmguide/tmg_2013/vehicle-types.cfm. Retrieved June 10.

FHWA. (2014). Chapter 2: Funding. Highway funding. Policy and Governmental Affairs. https://www.fhwa.dot.gov/policy/23cpr/chap2.cfm#revenue-sources-for-highways.

Ford, A. (1995). The impacts of large scale use of electric vehicles in southern California. *Energy and Buildings, 22*(3), 207–218. https://doi.org/10.1016/0378-7788(95)00923-L

GM. (2021). *GM launches BrightDrop, a new business that will Electrify and Improve the Delivery of Goods and Services.* Media.Gm.Com. https://media.gm.com/media/us/en/gm/home.detail.html/content/Pages/news/us/en/2021/jan/ces/0112-brightdrop.html.

Harto, C., & Baker-Branstetter, S. (2019). Rising trend of punitive fees on electric vehicles won't dent state highway funding shortfalls but will hurt consumers. Atlas EV hub. https://www.atlasevhub.com/resource/rising-trend-of-punitive-fees-on-electric-vehicles-wont-dent-state-highway-funding-shortfalls-but-will-hurt-consumers/.

Hauff, K., Pfahl, S., & Degenkolb, R. (2018). Taxation of electric vehicles in europe: A methodology for comparison. *World Electric Vehicle Journal, 9*(2), 30. https://doi.org/10.3390/wevj9020030

Huang, S. K., Kuo, L., & Chou, K.-L. (2018). The impacts of government policies on green utilization diffusion and social benefits – a case study of electric motorcycles in Taiwan. *Energy Policy, 119*, 473–486. https://doi.org/10.1016/j.enpol.2018.04.061

Indiana Department of Revenue. (2022b). Departmental notice #12. June 2022. *State and Federal Excise Taxes Levied on Motor Fuel.* https://www.in.gov/dor/files/reference/dn12.pdf.

IEA. (2019). *Global EV outlook 2019 – analysis*. IEA. https://www.iea.org/reports/global-ev-outlook-2019.

IEA. (2021). Trends and developments in electric vehicle markets – global EV Outlook 2021 – analysis. IEA. https://www.iea.org/reports/global-ev-outlook-2021/trends-and-developments-in-electric-vehicle-markets.

IEA. (2022). *Electric cars fend off supply challenges to more than double global sales*. IEA, Paris: IEA. https://www.iea.org/commentaries/electric-cars-fend-off-supply-challenges-to-more-than-double-global-sales.

Indiana Department of Revenue. (2022a). Miscellaneous tax rates. Miscellaneous tax rates. https://www.in.gov/dor/business-tax/tax-rates-fees-and-penalties/miscellaneous-tax-rates/.

Indiana Legislative Services Agency. (2018). Indiana handbook of taxes, revenues and appropriations. *Office of Fiscal and Management Analysis.* https://www.lincolninst.edu/sites/default/files/gwipp/upload/sources/Indiana/2018/in_indiana_handbook_of_taxes_revenues_and_appropriations_legislative_services_agency_office_of_fiscal_and_management_analysis_nov_2018.pdf.

INDOT. (2019). INDOT mission Goals and values. Strategic plan. *INDOT Strategic Plan.* https://www.in.gov/indot/about-indot/indot-mission-goals-and-values/.

Infrastructure Investment and Jobs Act. (2021). Public law No: 117-58. *H.R.3684—117th Congress (2021-2022). (2021/2022) [Legislation].* https://www.congress.gov/bill/117th-congress/house-bill/3684/text. (Accessed 15 November 2021).

Iowa DOT. (2018). *2018 Report on the Impact of electric Vehicles to the road use tax fund* [departmental report]. http://publications.iowa.gov/29142/.

Jenn, A., Azevedo, I. L., & Fischbeck, P. (2015). How will we fund our roads? A case of decreasing revenue from electric vehicles. *Transportation Research Part A: Policy and Practice, 74*, 136–147. https://doi.org/10.1016/j.tra.2015.02.004

Jia, W., Jiang, Z., Chen, T. D., & Paleti, R. (2019). Evaluating fuel tax revenue impacts of electric vehicle adoption in Virginia counties: Application of a bivariate linear mixed count model. *Transportation Research Record: Journal of the Transportation Research Board, 2673*(9), 548–561. https://doi.org/10.1177/0361198119844973

Johnson, C., Nobler, E., Eudy, L., & Jeffers, M. (2020). Financial analysis of battery electric transit buses (NREL/TP-5400–74832). *National Renewable Energy Laboratory.* https://www.worldtransitresearch.info/research/8100.

Jones, K., & Bock, M. (2017). Oregon's road usage charge. The OReGO program. *Final Report. Oregon Department of Transportation.* https://www.oregon.gov/odot/Programs/RUF/IP-Road%20Usage%20Evaluation%20Book%20WEB_4-26.pdf.

Knoema. US Inflation Forecast: 2021, 2022 and long Term to 2030. Data and charts. Knoema. n.d https://knoema.com//kyaewad/us-inflation-forecast-2021-2022-and-long-term-to-2030-data-and-charts. (Accessed 11 July 2021).

Konstantinou, T. (2019). *Market adoption and impact of electric roadways on criteria pollutants and greenhouse gas emissions.* Thesis. *Purdue University Graduate School.* https://doi.org/10.25394/PGS.7429100.v1.

Konstantinou, T. (2022). *Evaluating the potential of truck electrification and its implementation from user and agency perspectives* (Version 1). Purdue University Graduate School. doi: https://doi.org/10.25394/PGS.20380455.v1.

Labi, S. (2014). Introduction to Civil engineering systems. *A systems perspective to the development of Civil Engineering Facilities* (John Wiley & Sons, Inc).

Lambert, F. (2018). UPS is buying a fleet of 1,000 electric vans from Workhorse. *Electrek.* https://electrek.co/2018/06/15/ups-fleet-1000-electric-vans-workhorse/.

Lion Electric. (2021). Lion electric Secures its largest truck Order to Date with 100 zero-emission Trucks from pride group enterprises. March 25 *Press release* https://thelionelectric.com/img/medias/LION_Press_Release_Pride_FINAL_EN.pdf.

Macioszek, E. (2021). The role of incentive programs in promoting the purchase of electric cars—review of good practices and promoting methods from the world. In E. Macioszek, & G. Sierpiński (Eds.), *Research methods in modern urban transportation systems and networks* (pp. 41–58). Springer International Publishing. https://doi.org/10.1007/978-3-030-71708-7_4.

Manthey, N. (2021). SEA Electric scores its biggest e-truck deal to date. Electrive.Com. https://www.electrive.com/2021/10/21/sea-electric-writes-largest-order-of-electric-trucks-to-date/.

Matousek, M. (2018). Tesla has a new customer for its electric Semi—here are all the companies that have ordered the big rig. Business Insider. https://www.businessinsider.com/companies-that-ordered-tesla-semi-2017-12.

M.J. Bradley & Associates. (2018). Electric vehicle cost-benefit analysis. *Plug-in electric vehicle cost-benefit analysis*. Indiana https://mjbradley.com/sites/default/files/IN%20PEV%20CB%20Analysis%20FINAL.pdf.

Muratori, M., Alexander, M., Arent, D., Bazilian, M., Dede, E. M., Farrell, J., Gearhart, C., Greene, D., Jenn, A., Keyser, M., Lipman, T., Narumanchi, S., Pesaran, A., Sioshansi, R., Suomalainen, E., Tal, G., Walkowicz, K., & Ward, J. (2021). The rise of electric vehicles—2020 status and future expectations. Progress in Energy, 3(2), 022002 https://doi.org/10.1088/2516-1083/abe0ad.

NCSL. (2022). Special Fees on plug-in Hybrid and electric vehicles. NCSL. *https://www.ncsl.org/research/energy/new-fees-on-hybrid-and-electric-vehicles.aspx*.

NESCAUM. (2021). Multi-state medium- and heavy-duty zero emission vehicle Memorandum of understanding. *https://www.nescaum.org/documents/mhdv-zev-mou_12-14-2021.pdf/*.

Pennsylvania Department of Revenue. Alternative fuels tax rates. Pennsylvania Department of revenue. *https://www.revenue.pa.gov:443/Tax%20Rates/Pages/Alternative%20Fuels%20Tax%20Rates.aspx*.

Peterbilt. (2021). Peterbilt delivers model 579EVs to shippers transport express. *Peterbilt*. *https://www.peterbilt.com/about/news-events/news-releases/peterbilt-delivers-model-579EVs-to-shippers-transport-express*.

Plug In America. (2020). Transportation Funding and EV fees. [White paper]. https://pluginamerica.org/wp-content/uploads/2020/08/PIA-EV-Fees_-white-paper_August2020-1.pdf.

Ricciuti, J. (2020). *Impact of lost gas tax revenue due to sale of electric vehicles: Analysis and recommendations for the 50 states*. Thesis. La Salle University https://digitalcommons.lasalle.edu/analytics_capstones/2.

Schleith, K. (2015). Implications of electric vehicles on gasoline tax revenues (FSEC-CR-2011-15). Electric vehicle transportation center. http://www.fsec.ucf.edu/en/publications/pdf/FSEC-CR-2011-15.pdf.

SEA Electric. (2019). SEA Electric wins 100-truck order in US. *https://www.sea-electric.com/sea-electric-wins-100-truck-order-in-us/*.

Shan, L., Garvin, M. J., & Kumar, R. (2010). Collar options to manage revenue risks in real toll public-private partnership transportation projects. *Construction Management & Economics, 28*(10), 1057–1069. https://doi.org/10.1080/01446193.2010.506645

Short, J., & Crownover, D. (2021). Electric vehicles and infrastructure funding technical memorandum (p. 30. ATRI https://truckingresearch.org/2021/09/28/electric-vehicles-and-infrastructure-funding-technical-memorandum/.

Smith, D., Ozpineci, B., Graves, R., Jones, P. T., Lustbader, J., Kelly, K., Walkowicz, K., Birky, A., Payne, G., Sigler, C., & Mosbacher, J. (2019). *Medium- and heavy-duty vehicle electrification: An Assessment of Technology and knowledge gaps* (ORNL/SPR-2020/7). *Oak Ridge National Laboratory (ORNL) and National Renewable Energy Laboratory (NREL)*. https://info.ornl.gov/sites/publications/Files/Pub136575.pdf.

Stinson, J. (2020). Kenworth to produce its first Class 8 battery-electric truck in 2021. October 16 *Utility Dive* https://www.utilitydive.com/news/Kenworth-T680E-first-electric-Class-8-truck-model/587221/.

Szybist, M., & Harris, K. (2019). *PA's gas Tax and proposed electric vehicle fees: A primer*. NRDC. https://www.nrdc.org/experts/mark-szybist/electric-vehicle-taxes-pa-what-you-need-know.

The White House, Office of the Press Secretary. (2021). President biden announces steps to drive American leadership forward on clean cars and trucks. (Fact sheet). https://www.whitehouse.gov/briefing-room/statements-releases/2021/08/05/fact-sheet-president-biden-announces-steps-to-drive-american-leadership-forward-on-clean-cars-and-trucks/.

Tomlinson, V. (2020). UPS invests in arrival and orders 10,000 generation 2 electric vehicles. Arrival.Com. https://www.arrival.com/us/en/news/ups-invests-in-arrival-and-orders-10000-generation-2-electric-vehicles.

Trinko, D., Horesh, N., Zane, R., Song, Z., Kamineni, A., Konstantinou, T., Gkritza, K., Quinn, C., Bradley, T. H., & Quinn, J. C. (2022). Economic feasibility of in-motion wireless power transfer in a high-density traffic corridor. *ETransportation, 11*, Article 100154. https://doi.org/10.1016/j.etran.2021.100154

U.S. Bureau of Labor Statistics. (n.d.). Consumer Price Index (CPI) Databases. CPI for All Urban Consumers (CPI-U). Division of Consumer Prices and Price Indexes. https://www.bls.gov/cpi/data.htm.

Valenta, M. (2013). *Business case of electric vehicles for truck fleets. [Doctoral Dissertation]. Argosy University*.

Varma, A., & Sinha, K. C. (1990). On user charges for highway financing. *Transportation Research Part A: General, 24*(4), 293–302. https://doi.org/10.1016/0191-2607(90)90006-R

Varn, J., Garrett, E., & Gander, S. (2020). Planning for state transportation revenue in a coming era of electric vehicles (p. 19) [white paper]. *National Governors Association Center for Best Practices*. https://www.nga.org/wp-content/uploads/2020/02/White-Paper-Planning-for-State-Transportation-Revenue-in-a-Coming-Era-of-Electric-Vehicles.pdf.

Vasudevan, V., & Nambisan, S. S. (2014). Impacts of energy regulations and vehicular technologies on fuel tax revenues. *Journal of Infrastructure Systems. ASCE., 20*(2). https://doi.org/10.1061/(ASCE)IS.1943-555X.0000184, 04014007.

Volvo. (2021). Volvo takes largest order of electric trucks in North America. https://www.volvogroup.com/en/news-and-media/news/2021/sep/news-4055688.html.

Watts, R., Trapenberg Frick, K., & Maddison, J. (2012). Policy making, incrementalism, and news discourse gasoline tax debates in eight U.S. States. *Public Works Management & Policy, 17*(3), 238–255. https://doi.org/10.1177/1087724X12437220

Whitty, J. M. (2007). Oregon's mileage fee Concept and road user fee pilot program. Oregon DOT. https://www.myorego.org/wp-content/uploads/2017/07/RUFPP_finalreport.pdf.

Xu, D., Zhou, H., Xue, C., & LaMondia, J. (2020). Impact of electric and hybrid vehicles on highway Trust fund in Alabama. *Transportation Research Record, 2674*(9), 913–921. https://doi.org/10.1177/0361198120932901