MARCH 2025

Challenges and opportunities for the zero-emission vehicle transition in rural regions

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ZEV ALLIANCE

The International Zero-Emission Vehicle Alliance is a network of leading national and sub-national governments demonstrating their deep commitment to accelerating the transition to zero-emission vehicles within their markets and globally. Its members include Austria, Baden-Württemberg, British Columbia, California, Canada, Chile, Connecticut, Costa Rica, Germany, Maryland, Massachusetts, the Netherlands, New Jersey, New York, New Zealand, Norway, Oregon, Québec, Rhode Island, Switzerland, the United Kingdom, Vermont, and Washington. The members collaborate through discussion of challenges, lessons learned, and opportunities; hosting events with governments and the private sector; and commissioning research on the most pressing issues in the ZEV transition.

Acknowledgments

This work was conducted for the International Zero-Emission Vehicle Alliance by the International Council on Clean Transportation (ICCT). The authors thank Logan Pierce and Kaylin Lee for reviewing an earlier version of the report. We also extend our appreciation to the members of the International Zero-Emission Vehicle Alliance who provided key input on policy activities and reviewed an earlier version of the report; their review does not imply an endorsement.

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Executive summary

As the transition to zero-emission vehicles (ZEVs) accelerates around the world, there are concerns about an uneven pace across different equity dimensions, including between urban and rural regions. Ensuring a smooth ZEV transition in rural regions is important not just from an equity perspective, but also because rural regions tend to have greater car dependence and more vehicle miles traveled, at least in developed economies.

This report examines the opportunities and challenges for a ZEV transition in rural regions by first evaluating the extent to which disparities exist in ZEV uptake between urban and rural regions in Germany and the U.S. state of New York and then exploring potential explanations for these differences. Based on a review of literature and interviews with rural ZEV users in North America and Europe, we then discuss different steps that can be taken to accelerate the ZEV transition in rural regions. The report's main findings are summarized below.

Rural regions in Germany are outperforming urban regions in battery electric vehicle (BEV) adoption, while rural regions in New York state are substantially behind urban regions. In 2023, 63% of the 110 rural regions in Germany had BEV registration shares of new passenger car registrations equal to or above the national average of 18%. In comparison, 56% of the 95 urban regions in Germany had rates equal to or above the national average. This is similar to previous years. In New York in 2023, 36% of the 22 urban regions had BEV registration shares of new cars and light trucks (collectively referred to as light-duty vehicles) registrations equal to or above the state average of 5.3%, while no rural regions were at or above the average. Figure ES1 compares BEV shares of new vehicle registrations with the national average (Germany) or with the state average (New York state) in rural, intermediate (with urbanization levels between rural and urban regions), and urban regions in Germany and New York state.

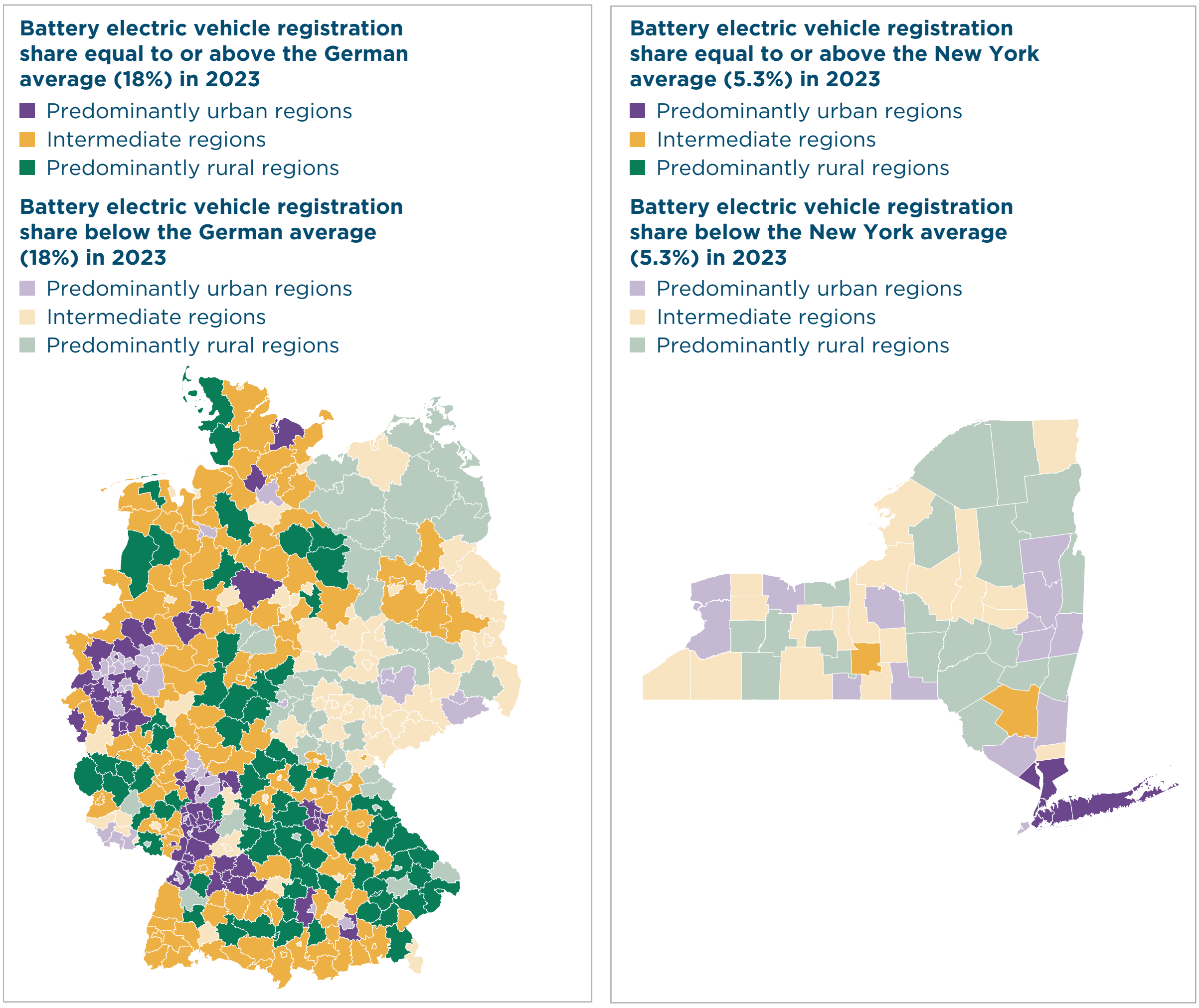

Figure ES1. Battery electric vehicle share of new passenger cars (Germany) and cars and light trucks (New York) registrations in 2023 by rural, intermediate, and urban regions compared with the national or state average

There is evidence of varying patterns and degrees of association between urbanization, income, and public charging deployment and urban-rural disparities in BEV uptake in Germany and New York state. In New York state, no rural region has a BEV share of new light-duty vehicle registrations equal to or above the state average. Although eight out of the state's 22 urban regions are at or above average, all are clustered around the New York metropolitan area. Furthermore, we find a high statistical correlation between income and BEV registration share in New York state while in Germany, 63% (65/103) of below-average income rural regions have equal to or above-average BEV registration shares. Similarly, the per-capita public charging points metric, which includes both alternating current (AC) and direct current (DC) chargers, is above average for about 80% of rural regions in Germany, which aligns well with 63% of rural regions having BEV registration shares equal to or above the national average. However, 27% of rural German regions have an above-average number of AC charging points but below-average BEV registration shares, while in New York state 50% of rural counties have above-average AC charging points while no rural New York county has an equal to or above-average BEV registration share.

In interviews, rural BEV users highlighted lack of awareness as a key barrier. All 14 individuals interviewed, located across North America and Europe, were highly satisfied with their decision to switch to electric cars. The interviewees cited ease of home charging combined with the performance characteristics of BEVs (e.g., higher acceleration) on narrow rural roads as important positives. While they also said that oft-cited challenges like affordability, public charging adequacy, and power supply and grid issues remain, they felt that some prevalent perceptions of the capabilities of BEVs are outdated and do not reflect the progress in BEV range and charging infrastructure availability in recent years.

Targeted awareness-building campaigns could accelerate the rural ZEV transition. Things like test drive and car sharing programs that encourage users to borrow or rent a BEV for a short period for free or minimal charge can be useful. One example is the Rural Reimagined test drive program focused on select economically distressed Appalachian communities in the United States. Awareness-building efforts can also increase the effectiveness of other strategies aimed at promoting BEV adoption. Evidence of this was found in two rural regions, one in Germany and the other in New York state, with above-average BEV registration shares explored as case studies. Finally, strategies for promoting BEV adoption can target a broad category of low-uptake areas that encompasses rural regions. For example, Scotland provides government-funded, interest-free loans for purchasing a used electric car to residents of small towns, rural and remote areas, or islands, and Austria promotes the construction of public fast chargers in underserved areas that do not have fast charging within a 7 km radius through its LADIN infrastructure program.

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Introduction

The transition to zero-emission vehicles (ZEVs) is progressing globally.[1] In 2023, 9.5 million new battery electric vehicles (BEVs) were registered, up more than 20% from the over 7.3 million registered in 2022 (International Energy Agency [IEA], 2024). An accelerated transition to ZEVs is not only crucial to attaining Paris Agreement climate goals (Sen et al., 2023) but also offers the co-benefits of reduced air pollution and improved public health outcomes.

While the overall progress is positive, concerns have been raised about an uneven pace of transition across various equity dimensions, including developed economies compared with emerging markets and developing economies (ZEV Transition Council, 2023), vehicle users with lower versus higher incomes (Sovacool et al., 2019), and disparities between urban and rural areas (Wappelhorst, 2021). There are various reasons to be interested in the ZEV transition in rural regions in particular. As rural regions in developed economies are associated with higher car dependence and vehicle-miles traveled (Federal Highway Administration, 2022), this implies a higher contribution to greenhouse gas emissions per vehicle. Additionally, although some studies have highlighted the need to ensure access to electric vehicles in rural regions so that all communities can partake in their economic and environmental benefits (Wappelhorst, 2021), the bulk of research on ZEVs to date is urban-focused (McKinney et al., 2023). This leaves a gap in the literature from which policymakers can draw insights.

In this context, this study examines the opportunities and challenges for a ZEV transition in rural regions. We draw on existing literature and conduct our own empirical research to investigate whether disparities exist in ZEV uptake between urban, intermediate (with urbanization levels between urban and rural regions), and rural regions in Germany and the state of New York in the United States. We then examine various potential explanations for the disparities and evaluate how opportunities can be leveraged to address challenges.

The study presents a quantitative and geospatial comparative analysis for urban and rural regions in Germany and the state of New York from secondary data of BEV registrations, public charging infrastructure deployment, and household income. We also conducted statistical analysis to detect potential correlations between variables and performed a closer examination of two rural regions, one in Germany and one in New York, that have above-average BEV registration share. We additionally conducted interviews with a small sample of rural BEV owners in North America and Europe and a literature review of good practices in terms of policy deployments. Based on the findings, we discuss steps that can be taken to accelerate the ZEV transition in rural regions and present an overview of policy practices from leading governments.

Urban-rural dichotomy

Urban areas are typically defined as settlements with a relatively high density of population or development or a high population size, and the thresholds for density and population size vary across jurisdictions. Rural areas are often defined by negation as all that is not urban. In some instances, "intermediate" regions are also defined as those with population size or densities

1 This study focuses on battery electric passenger cars, as well as light trucks in North America, and the terms battery electric vehicle (BEV) and zero-emission vehicle (ZEV) are used interchangeably. We recognize hydrogen fuel-cell electric vehicles as ZEVs, but they were not a large portion of passenger car registrations in recent years and are not the focus of this study.

between the urban and rural thresholds; in others, sub-categories are created for rural and urban, such as in England, where there are "urban with significantly rural" and "largely rural" areas (Office for National Statistics, 2017). An overview of the approaches to defining urban and rural areas in select jurisdictions is provided in Appendix A.

While the nuances of the definitions are not pertinent to understanding the results of this study, the urban-rural demarcation is significant for public policy and governance across sectors, as the challenges and solutions in the ZEV transition often vary considerably between rural and urban areas (Office for National Statistics, 2017). For instance, the deployment of high-frequency public transport systems is often considered unviable in low-density rural areas for want of justifiable passenger demand (Porru et al., 2020) and viable in cities with larger populations and high-volume travel demand. This has contributed to greater car dependency in rural areas in developed economies (Gray, 2004).

Insights from literature

Our review of the growing body of literature on the rural-urban divide in the ZEV transition suggests the dynamics are complex. This complexity is examined here along three interrelated dimensions: disparities between rural and urban ZEV uptake; potential reasons behind the disparities; and whether such disparities are unique to the ZEV transition.

First, within extant literature, disparities between ZEV uptake in rural and urban areas vary across jurisdictions. Broadly, there is evidence of cities leading the ZEV transition. The twenty-five metropolitan areas that accounted for 32% of total global new electric vehicle registrations (battery electric and plug-in hybrid electric vehicles) in 2020 were home to only 13% of all new vehicle registrations globally that year and 4% of the global population (Bernard et al., 2021). In China, where almost 35% of the population lives in rural regions (Jin & Chu, 2023), the top 30 city markets alone were home to almost 70% of all new energy vehicle sales in 2020 (Chu et al., 2022).[2] The disparity is attributed to high upfront purchase costs for electric vehicles, the lower average disposable income of rural residents compared with urban, and limited access to BEV information, products, and services in rural areas (Jin & Chu, 2023). Similarly, 2020 data showed BEV ownership was higher in urban regions than rural regions in California, and relative differences in income levels were cited as a potential reason (Robinson et al., 2023).

In contrast, an ICCT study of BEV uptake in Germany based on 2022 data found that 56% of rural and intermediate regions were at or above the German national average for BEV registrations by private individuals, and in urban regions, only 33% had BEV registration shares equal to or above the national average (Wappelhorst et al., 2023). There is also evidence of some rural regions outperforming urban regions more generally across Europe (Morrison & Wappelhorst, 2022).

Secondly, a wide range of potential factors, not necessarily grounded in empirical studies and often agnostic of jurisdiction, have been put forth to explain slower ZEV uptake in rural areas since the early days of the transition (e.g., Aultman-Hall et al., 2012) and some have questioned the idea that ZEVs are more compatible with urban areas (e.g., Kester et al., 2020; Newman et al., 2014). Potential barriers in the literature can be put into two categories: those that are typically applicable to both

2 In China, the term new energy vehicle encompasses battery electric, plug-in hybrid electric, and hydrogen fuel-cell electric vehicles.

rural and urban regions but may be more pronounced in rural regions, and those that are typically only applicable to rural regions.

Within the first category, issues around range anxiety and inadequate public charging infrastructure deployment in rural areas, usually driven by lack of a business case (ICF & Cenex, 2024), have often been highlighted (Federal Highway Administration, 2022). Meanwhile, the average range of medium-size cars and sport utility vehicles has increased to about 380 km as of 2023, up from around 150 km for medium cars and 270 km for sport utility vehicles in 2015, which is encouraging for drivers for long journeys and non-urban use (IEA, 2024). Furthermore, there is evidence of a positive correlation between average disposable income and BEV shares in new passenger car registrations in rural regions in Germany (Wappelhorst et al., 2022). Lack of awareness about BEVs and their usability (Esmene & Leyshon, 2019; U.S. Department of Transportation, 2023), environmental awareness (Wappelhorst et al., 2022), and higher educational attainment and political alignment with the Democratic party in the United States (Min & Mayfield, 2023) have also been associated with rates of adoption.

In the category of rural-only issues, insufficient diversity of BEV models in the segments prevalent in rural areas, such as pick-up trucks, is often offered as a barrier to adoption (Baatar et al., 2019; Robinson et al., 2023). However, this is changing rapidly: almost two-thirds of the battery electric models available in the global market in 2023 were sport utility vehicles, pick-up trucks, or large cars (IEA, 2024). Inadequate electricity supply or lack of appropriate infrastructure, such as the lack of a three-phase electricity supply that is crucial for fast charging (Hunter et al., 2023), can further impede uptake. Inadequate repair and maintenance capacity in rural areas is also cited as an issue (Pinto de Moura, 2023).

At the same time, the ease of setting up private home charging in rural areas that is enabled by the higher share of one- and two-family homes can be an advantage (Mann et al., 2014; Schippl & Truffer, 2020; Wappelhorst et al. (2022)). Moreover, BEVs tend to have lower per-mile fuel and maintenance costs compared with internal combustion engine vehicles (ICEVs). As such, it has been argued that the higher mileage associated with rural drivers helps bring down the total cost of ownership and makes rural areas potentially more attractive for a BEV transition than urban areas (e.g., Plötz et al., 2014; Robinson et al., 2023). A recent study based on social media data found that U.S. counties with higher percentages of rural population exhibited more positive sentiments toward electric vehicles (Wang et al., 2024).

Finally, evidence suggests that the rural-urban divide is not unique to the ZEV transition. There was widespread opposition to the transition to automobiles from horse carriages in the rural United States during the early 20th century, even as it had already started to take hold in cities (Kline & Pinch, 1996), and internet use in the rural United States has lagged urban areas almost consistently by 6 to 7 percentage points for most of the period since the 1990s (Carlson & Goss, 2016). A survey conducted in 2021 found that rural U.S. residents were less likely than their urban counterparts to have access to broadband, smartphones, or computers (Vogels, 2021). On the other hand, the adoption of solar water heaters in China began in rural areas and there were challenges to their adoption in urban areas (Yu & Gibbs, 2018).

To summarize, our review of the literature indicates that rural-urban disparities can vary across jurisdictions. Multiple factors that are location-agnostic can be associated with lower ZEV uptake in rural areas. These include inadequacy of public charging, affordability, and lack of awareness, among others. At the same time, ease of home charging and operational cost savings can work in favor of rural areas. Urban-rural disparities, insofar as they exist, are not unique to ZEVs and can be found across the spectrum of various technologies.

Our review suggests a lack of qualitative evidence backed by primary data to support claims about the challenges, opportunities, and strategies for accelerating BEV uptake in rural areas. Although only a few studies (e.g., Quallen et al., 2023) have examined the preferences and behavioral patterns of existing or potential users and non-users of BEVs in rural areas, such studies abound for urban areas. To a modest degree, this study aims to help address this gap by offering insights from interviews with BEV owners in North America and Europe. In addition, there is a need to further substantiate, update, and diversify evidence regarding variations within BEV adoption rates in rural and urban areas across different jurisdictions. Through case studies of Germany and the state of New York, this study helps expand this body of evidence.

Battery electric vehicle adoption in urban and rural regions in Germany and New York state

The urban, rural, and intermediate regions of Germany and the state of New York were chosen for analysis because they have BEV registration shares relatively similar to their broader regional averages (18% BEV registrations in total new passenger car registrations in Germany in 2023 compared with 15% in the European Union, and 5.3% in New York state compared with 8% in the United States). This makes the results potentially more relevant to other geographies. Moreover, both jurisdictions have a mix of large cities, small cities, and rural areas, and that is helpful for drawing meaningful comparisons.

Table 1 summarizes the classification system used for regions in New York state and Germany. This system is used consistently throughout the study to analyze BEV uptake and its relationship with potential explanatory factors. Given the differences in geography, travel patterns, and data availability, the definitions for Germany and New York differ both in the definition of urban population and in the thresholds used to define urban, intermediate, and rural regions.

For Germany, we adopted the EU classification for “predominantly rural,” “intermediate,” and “predominantly urban” of NUTS level 3 regions provided in Eurostat (2018). While several definitions of urban areas exist across different organizations or programs in the United States, we used the definition from the U.S. Census Bureau (2024a) because it provides county-level data on urban population percentages. We used these percentages to classify counties as “predominantly rural” (urban population ≤ 33.3%), “intermediate” (urban population > 33.3% and ≤ 66.6%), and “predominantly urban” (urban population > 66.6%). Note that the U.S. Census 2020 does not directly classify counties in this manner. Note, too, that we use “regions” in this report as a broad term to mean both districts and district-free cities in Germany and counties in New York state whenever they are referred to collectively.

Table 1. Urban, intermediate, and rural classification of regions in Germany and New York state

Jurisdiction	Unit of classification (total number)	Classification	Definition	Definition source	Number (percentage of total in the jurisdiction)	Share of population in New York state (2022) or Germany (2023)
New York state	County (62)	Predominantly rural	Percentage of urban population ≤ 33.3%	Urban population percentage based on U.S. Census 2020 definition of "urban" (see Appendix A) Demarcations for "predominantly urban," "intermediate," and "predominantly rural" set by the ICCT	20 (32%)	5%
		Intermediate	Percentage of urban population > 33.3% and ≤ 66.6%		20 (32%)	9%
		Predominantly urban	Percentage of urban population > 66.6%		22 (35%)	86%
Germany	NUTS level 3 regions representing districts and district-free cities (400)	Predominantly rural	Regions where at least 50% of the population lives in rural grid cells[a]	Eurostat (see Appendix A)	110 (27%)	16%
		Intermediate	Regions where more than 50% and up to 80% of the population lives in urban clusters		195 (49%)	41%
		Predominantly urban	Regions where more than 80% of the population lives in urban clusters		95 (24%)	44%

Note: Percentages may not sum to 100% due to rounding.

[a] Rural grid cells are those that are not identified as urban clusters or centers (a cluster of contiguous grid cells of 1 km^2 with a population density of at least 1,500 per km^2 and collectively a minimum population of 50,000).

Data provided by the New York State Department of Motor Vehicles (2024) were used to calculate new BEV registrations in the state in 2023 (in total ~45,000). For Germany, we used data provided by Dataforce (2024) based on data from Kraftfahrt-Bundesamt to calculate new BEV registrations in 2023 (in total ~524,000). The Dataforce data was analyzed in another ICCT study (Wappelhorst et al., 2024); this paper builds upon that analysis to draw out additional considerations for rural areas in a global context. The mean percentage of BEVs in total new passenger car registrations across Germany and New York state was used to classify each region as "above or equal to the (national or state) average" and "below (national or state) average." For simplicity, the former classification is referred to hereafter as "above average." This approach is based on an earlier ICCT study on a related subject (Wappelhorst, 2021) and is used consistently throughout this study when comparing regions in Germany and New York state against different parameters.

Table 2 provides a comparison of BEV shares of new vehicle registrations across urban, rural, and intermediate regions in Germany (passenger cars) and New York state (cars and light trucks – collectively referred to as light-duty vehicles). With 63% of the 110 rural regions in Germany showing new BEV registration shares above the 18% national average in 2023, as compared with 56% of the 95 urban regions, rural regions are outperforming urban regions in Germany. This is consistent with prior studies (Wappelhorst et al., 2022). In contrast, in New York state, the 22 urban regions are performing significantly better than rural, with 36% of urban regions and not a single one of the 20 rural regions having an above-average new BEV registration share in 2023. The stark contrast suggests that urban-rural disparities vary across regions, and the general perception of rural regions as lagging urban regions in BEV uptake may not be accurate when looking at the number of rural regions above the national or state average share in new BEV registrations.

Table 2. Registration shares of battery electric vehicles across urban, rural, and intermediate regions in Germany and New York state

Jurisdiction	Unit of analysis	Share of battery electric vehicles in new passenger car/ light-duty vehicle registrations in 2023	Percentage (actual ratio) of regions higher than country or state average of battery electric vehicle shares in new passenger car/ light-duty vehicle registrations
Germany	**Country**	**18%**	62% (246/400)
	Predominantly rural regions	21%	63% (70/110)
	Intermediate regions	19%	63% (123/195)
	Predominantly urban regions	17%	56% (53/95)
New York state	**State**	**5.3%**	16% (10/62)
	Predominantly rural counties	2.7%	0% (0/20)
	Intermediate counties	2.6%	10% (2/20)
	Predominantly urban counties	5.9%	36% (8/22)

We also observe different patterns in the geographical distribution of regions with above- and below-average BEV registration shares. Figure 1 shows the geographic distribution of rural, intermediate, and urban regions and counties equal to or above and below the German and New York state average; above-average regions are indicated by darker shades, and those below average appear in lighter shades.

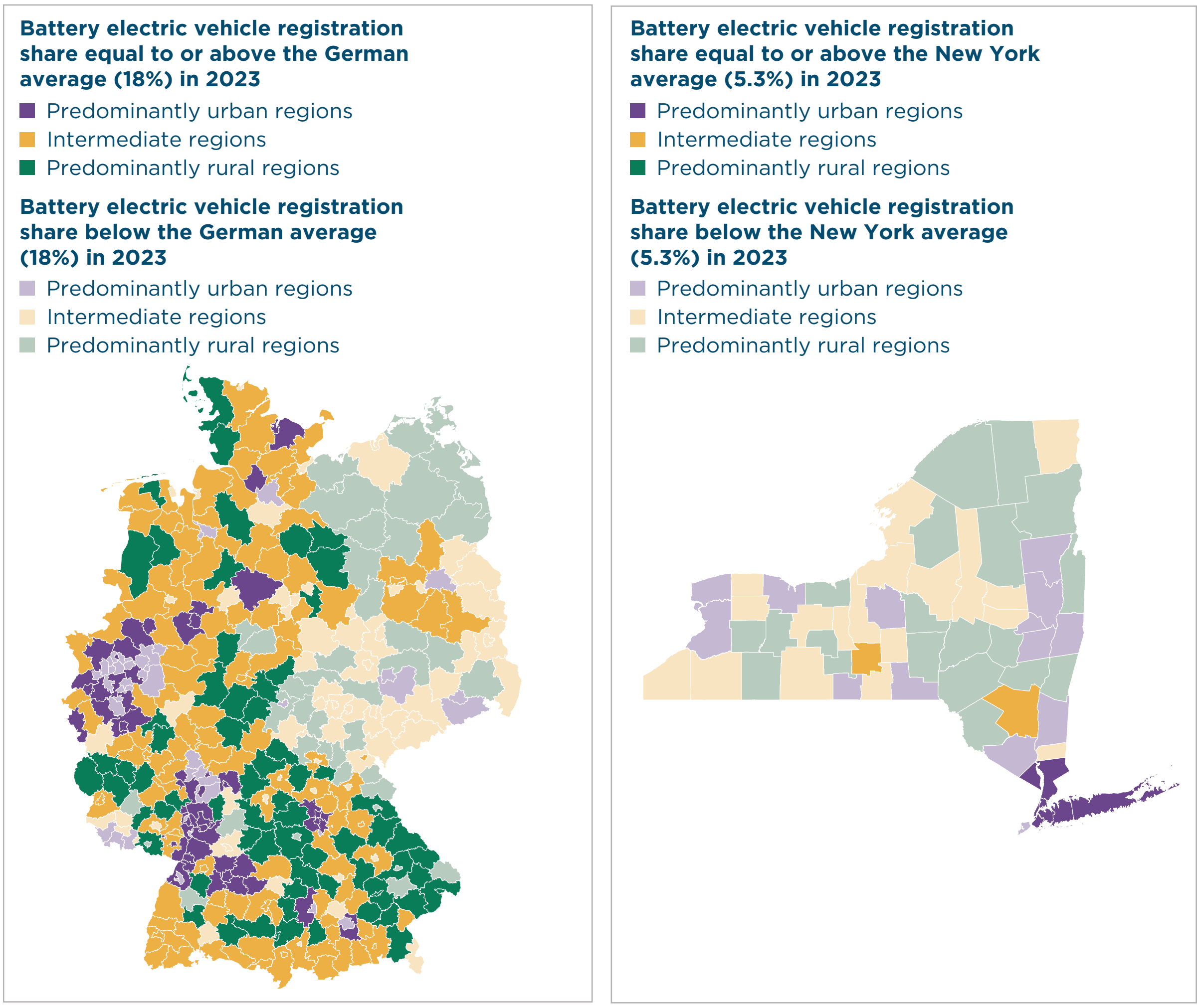


Figure 1. Share of total battery electric passenger car registrations in 2023 by rural, intermediate, and urban regions equal to or above and below the German and New York state average

In New York state, the eight urban counties that are above the state BEV registration share average are all clustered around the urban New York metropolitan area, the largest metropolitan area in the United States. It is also within this area that New York state counts some of its highest-income counties (U.S. Census, 2024b); this may be partially linked to the higher BEV shares, but proximity to a global megacity like New York City may have its own effects.

In Germany, meanwhile, the vast majority of above-average rural regions, 99% (68 out of 69), are located in the western, northern, and southern parts of the country, and 61% (25 out of 41) of the rural regions with below-average registration shares are located in the eastern part of Germany. This pattern holds true for urban and intermediate regions, too, and suggests that historical regional divides (Federal Ministry for Economic Affairs and Climate Action, 2021) that feature differences in demographic, socioeconomic, or socio-political characteristics could also manifest in BEV adoption patterns.

Potential factors associated with urban-rural disparities

To further investigate potential factors associated with urban-rural disparities in BEV adoption, we first show patterns in public charging infrastructure deployment and income levels across Germany and New York state. Next, we elaborate on the case of New York state, where the urban-rural disparities are more pronounced and offer some statistical insights on the potential dynamics. Finally, we perform a case study of a rural region in Germany and another in New York state, each of which has an above-average BEV share of new light-duty vehicle registrations. Note that the correlations discussed below do not imply causation and should not be interpreted as such.

Public charging infrastructure deployment

Data on public charging points from Eco-Movement (2024) show 10,300 alternating current (AC) points and 1,400 direct current (DC) points distributed across New York state's 62 regions as of January 1, 2024. In Germany, there were over 100,000 AC points and 23,000 DC points, also as of January 1, 2024. As a proxy for availability, we calculated the number of AC and DC charging points per 10,000 population and used the country or state average figures to determine the number of urban, rural, and intermediate regions performing above or equal to and below average in terms of public charging infrastructure deployment.[3] Table 3 compares AC and DC public charging deployment with the share of BEV registrations across urban, intermediate, and rural regions of Germany and New York state.

Table 3. Public charging deployment across urban, intermediate, and rural regions of Germany and New York state

Jurisdiction	Region type	Percentage (ratio) of regions with above-average		Percentage (ratio) of regions with above-average battery electric vehicle registration shares
		AC charging points per 10,000 population	DC charging points per 10,000 population	
Germany	Predominantly rural	82% (90/110)	78% (86/110)	63% (70/110)
	Intermediate	71% (139/195)	68% (132/195)	63% (123/ 195)
	Predominantly urban	37% (35/95)	32% (30/95)	56% (53/95)
New York state	Predominantly rural	45% (9/20)	35% (7/20)	0% (0/20)
	Intermediate	20% (4/20)	55% (11/20)	10% (2/20)
	Predominantly urban	36% (8/22)	45% (9/22)	36% (8/22)

In Germany, AC and DC public charging infrastructure deployment in rural regions is generally above the country average, which largely aligns with their above-average BEV registration shares.

3 We consider both public and semi-public charging points within our definition of public charging infrastructure. Fully public charging points are always accessible to the public without restrictions. Semi-public charging points include charging locations that may have certain access restrictions, like charging points on business premises like hotels or stores or within paid parking lots; these would not include private chargers available only to employees of one business or residents of one building, for example.

However, 27% (30/110) of rural regions have an above-average number of AC charging points and below-average BEV registration shares, and 8% (9/110) of rural regions have below-average AC charging points and above-average BEV registration shares. Regarding DC charging, 11% (12/110) of rural regions have a below-average number of DC charging points and above-average BEV shares, and 26% have above-average DC charging points and below-average BEV shares (29/110). As a similar pattern also emerges for urban regions, associations between public charging deployment and BEV registration shares appear to be inconsistent across different regions in Germany. In New York state, this contrast is even more pronounced: Almost 50% of rural counties have an above-average number of AC charging points, but not one rural New York state county has an above-average BEV registration share.

Overall, the evidence points toward patterns in public charging infrastructure deployment having a limited degree of association with the disparities in urban-rural BEV registration shares. A caveat here is the use of charging points per capita as a measure of deployment. Sparsely populated rural regions may appear to have adequate availability of charging points with this metric, but if the points are not spatially well distributed, they could be clustered around the population centers and leave vast spaces in between without any charging point. Moreover, many urban areas such as New York City can have lower car ownership than rural areas, and thus the same per-capita charging point availability can imply differing levels of availability per BEV. Although indicators that use area or highway length as the normalizing factor could potentially offer a more accurate picture for rural areas, these indicators can be unsuitable for urban areas, and robust data is usually not available across jurisdictions for charging points per kilometer of highway.

We also find a contrast in geographical patterns of public charging infrastructure deployment and BEV registration shares. Figures 2 and 3 show the geographic distribution of rural, intermediate, and urban regions and counties equal to or above and below the German and New York state average in terms of AC and DC public charging points per 10,000 inhabitants. In Germany (Figure 2), we do not see the same east-west divide in charging deployment that appears in BEV registration shares. Rural regions with an above-average number of AC charging points are located all across Germany, including eastern Germany where all but two of the eastern rural regions are above the German average. Moreover, rural regions with below-average access to DC points exist mostly in the southern and central parts of the country. No rural regions in eastern Germany have DC charging points per inhabitant under the national average. These trends are similar to those observed in Wappelhorst et al. (2022), which used 2020 electric vehicle sales data.

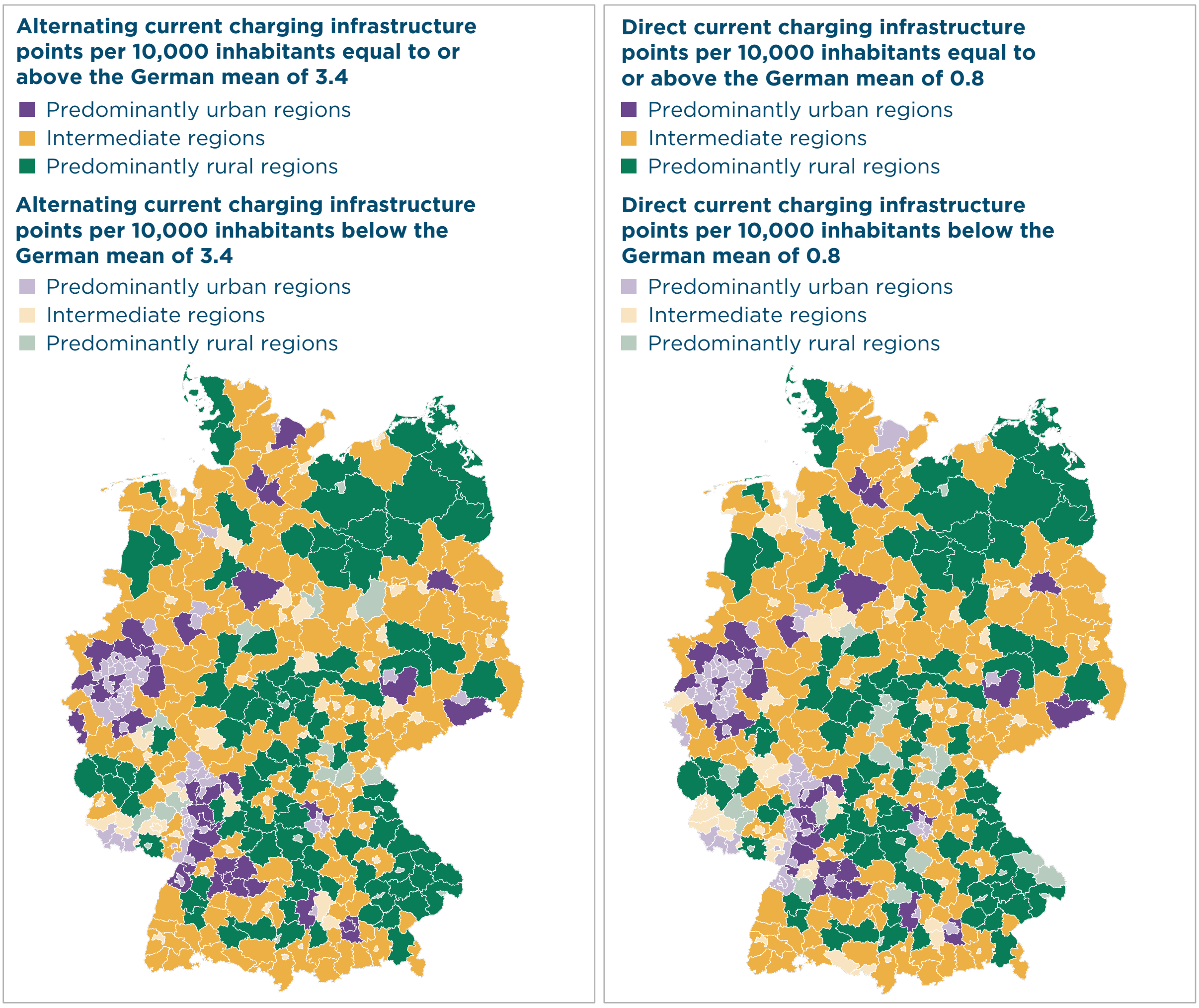


Figure 2. Public AC and DC charging points per 10,000 inhabitants in rural, intermediate, and urban regions in Germany in 2023

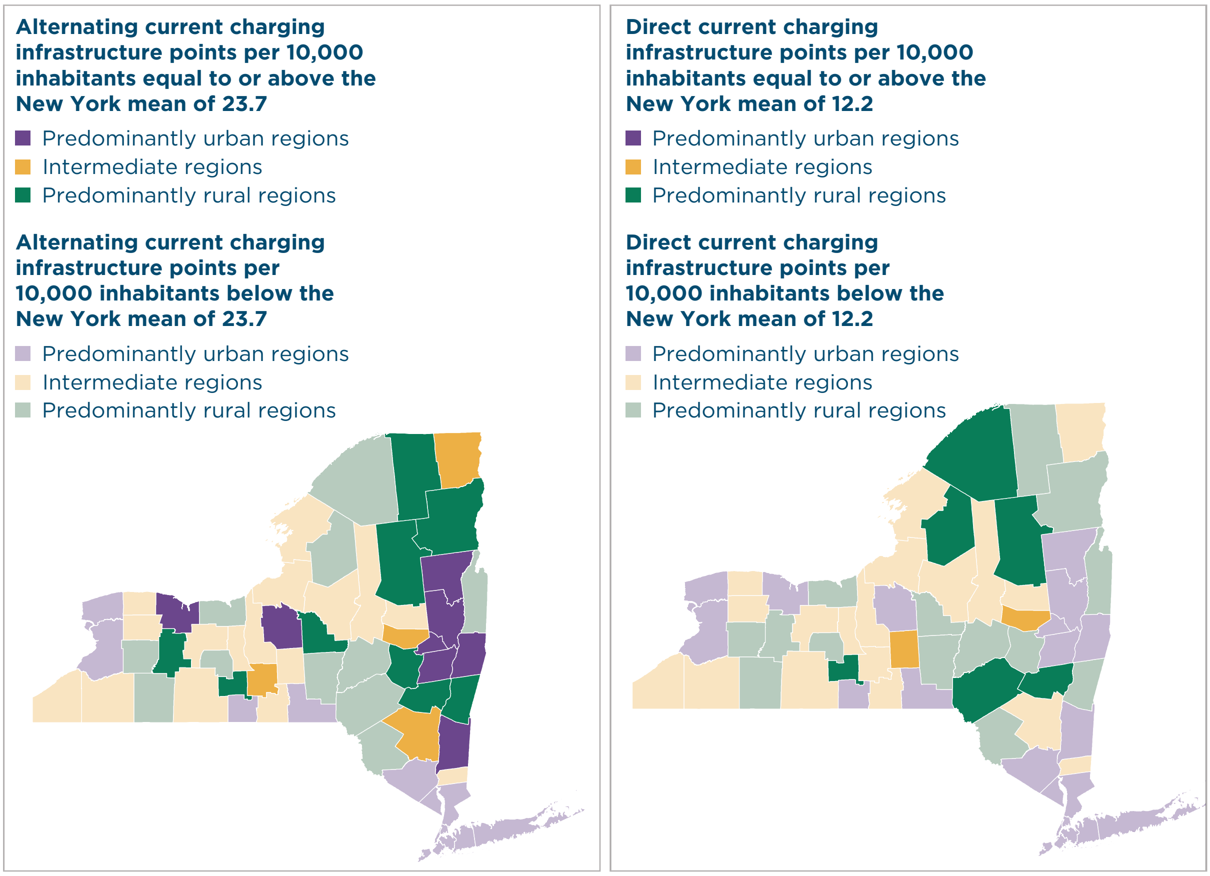


Figure 3. Public AC and DC charging points per 10,000 inhabitants in rural, intermediate, and urban counties in the state of New York in 2023

Similarly, in New York, we find little alignment between the location of counties with above-average charging infrastructure deployment and those with above-average BEV registration shares. For AC charging, all counties with an above-average number of charging points are outside of the New York metropolitan area, either in the northern or western central part of the state. Additionally, while some urban counties around the New York metropolitan area have above-average DC charging deployment, many above-average counties are spread out across the state.

Rather than finding a clear link between public charging deployment and BEV registration share, we instead see several instances of high dissonance between the two, like eastern Germany, where most of the rural regions are below the national BEV registration share average and yet nearly all have above-average deployment of DC public charging infrastructure. This disconnect cannot be understood better without examining the deployment of home charging, and that is not covered in this study.

Income levels

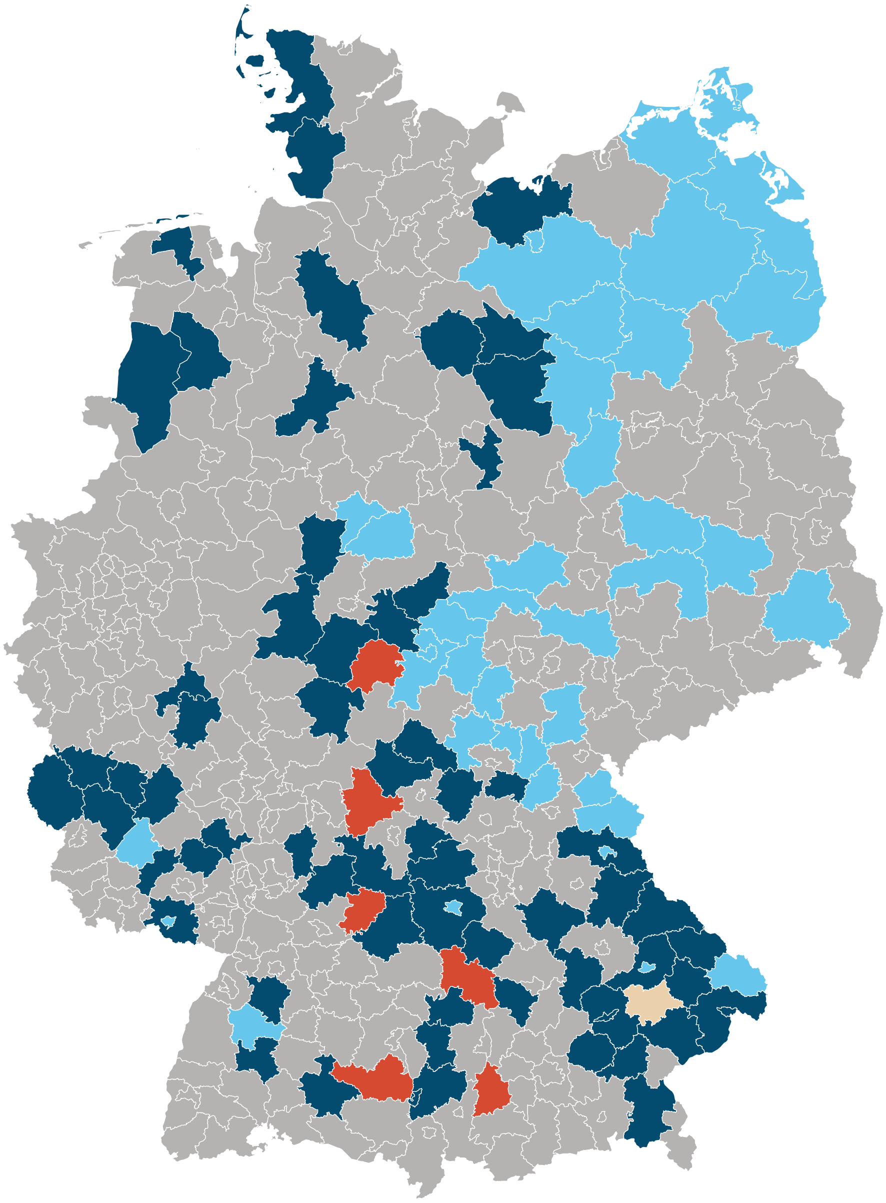
For New York state, we used county-level mean household income data from the U.S. Census Bureau (2024b). The data are based on a 5-year average from 2018 to 2022 and defined as “income received on a regular basis (exclusive of certain money receipts such as capital gains) before payments for personal income taxes, social security, union dues, [and] Medicare deductions." For Germany, we used mean gross wages and salaries per employee. Gross wages are defined as salaries that include income tax and social security contributions. We used the country or state mean income level—€39,777 ($44,237) in Germany in 2022 (Statistische Ämter des Bundes und der Länder, 2024) and $120,883 in New York state in 2022 (U.S. Census Bureau, 2024b)—to classify each rural region as "equal to or above average income" or "below-average income." Then we classified each rural region into four categories that help highlight potential linkages between income levels and BEV registration share. Table 4 provides a comparison of income levels and BEV registration shares in rural regions in Germany and New York state.

Table 4. Income levels and battery electric vehicle registration shares in rural regions in Germany and New York state

Category of rural region	Percentage (ratio) of rural regions in Germany	Percentage (ratio) of rural regions in New York state
Above-average income and above-average BEV registration share	5% (6/110)	0% (0/20)
Above-average income and below-average BEV registration share	0.01% (1/110)	0% (0/20)
Below-average income and above-average BEV registration share	60% (65/110)	0% (0/20)
Below-average income and below-average BEV registration share	35% (38/110)	100% (20/20)

Rural regions tended to have below-average mean incomes in both Germany (103 of 110 rural regions) and New York state (all 20 rural counties), but the patterns of association of incomes with BEV registrations differ. In New York state, all rural counties have both below-average incomes and below-average BEV registration shares. Somewhat similarly, six out of seven rural regions in Germany with above-average incomes also have above-average BEV registration shares. However, 63% (65/103) of rural regions in Germany with below-average income show above-average BEV share. Based on this alone, it is difficult to detect linkages between mean regional income and BEV share in Germany.

Furthermore, the divide between northern, western, southern versus eastern parts in Germany appears again in this case. Figure 4 shows the geographic distribution of rural regions in Germany classified in terms of their relative standing in income levels and BEV registration shares. Most of the regions with below-average gross income levels and below-average BEV shares are in eastern Germany.



- Above average income of €39,777 in 2022, and above or equal to the 18% total BEV share
- Above average income of €39,777 in 2022, and below the 18% total BEV share
- Below average income of €39,777 in 2022, and above or equal to the 18% total BEV share
- Below average income of €39,777 in 2022, and below the 18% total BEV share
- Intermediate and urban NUTS 3 regions

Figure 4. Income levels and battery electric vehicle registration shares in rural regions in Germany

Statistical insights

To further investigate the dynamics in New York state where urban-rural disparities seem evident, we examined statistical correlations between BEV registrations and potential factors like AC and DC charging points per capita, mean household income, and percentage of urban population. A more comprehensive statistical analysis was conducted for Germany using multiple variables, including environmental awareness, public charging infrastructure, home charging potential, and economic well-being, in Wappelhorst et al. (2022). Using county-level mean household income and urban population percentage data from the U.S. Census Bureau (2024a, 2024b), as well as the Eco-Movement (2024) database, we calculated Pearson's correlation coefficients and categorized the coefficients as strong, moderate, and weak to determine the extent to which BEV registrations were correlated with the factors described above. We considered a coefficient between +/- 0.50 and +/- 1 as indicative of a strong linear correlation, between +/- 0.30 and +/- 0.49 as a moderate linear correlation, and between -0.29 and +0.29 as a weak linear correlation. We also calculated the p-value of these linear correlations. A p-value of less than 0.05 indicates that the relationship is statistically significant, meaning that the observed correlation is unlikely to be due to random chance. The results are shown in Table 5, and figures in bold indicate relevant results.

Table 5. Pearson correlation coefficients between battery electric vehicle registration shares and potential explanatory factors for New York state

Potential explanatory factors	AC charging points per 10,000 capita	DC charging points per 10,000 capita	Mean household income	Urban population percentage
Pearson correlation coefficient with BEV share percentage	-0.03	-0.26	**0.72**	**0.61**
p-value	0.54	**≪ 0.05**	**≪ 0.05**	**≪ 0.05**

Note: Values in bold indicate strong linear correlation (relative to the Pearson correlation) or statistical significance relative to the p-value.

The strong positive linear correlation between BEV share and the share of urban population (coefficient of +0.61) and mean household income (coefficient of +0.72) are both statistically significant. While the data show that counties with a higher share of their population in urban areas typically have higher BEV registration shares and counties with higher mean household income also tend to have higher BEV registration shares, in New York, the 20 regions with the lowest fraction of population living in urban areas all had below-average income. While the share of urban population and mean household income both positively influence BEV share, it is not possible to disentangle the effects of these two variables. The data points describing these relationships are plotted in Figure 5 with trendlines illustrating their overall patterns.

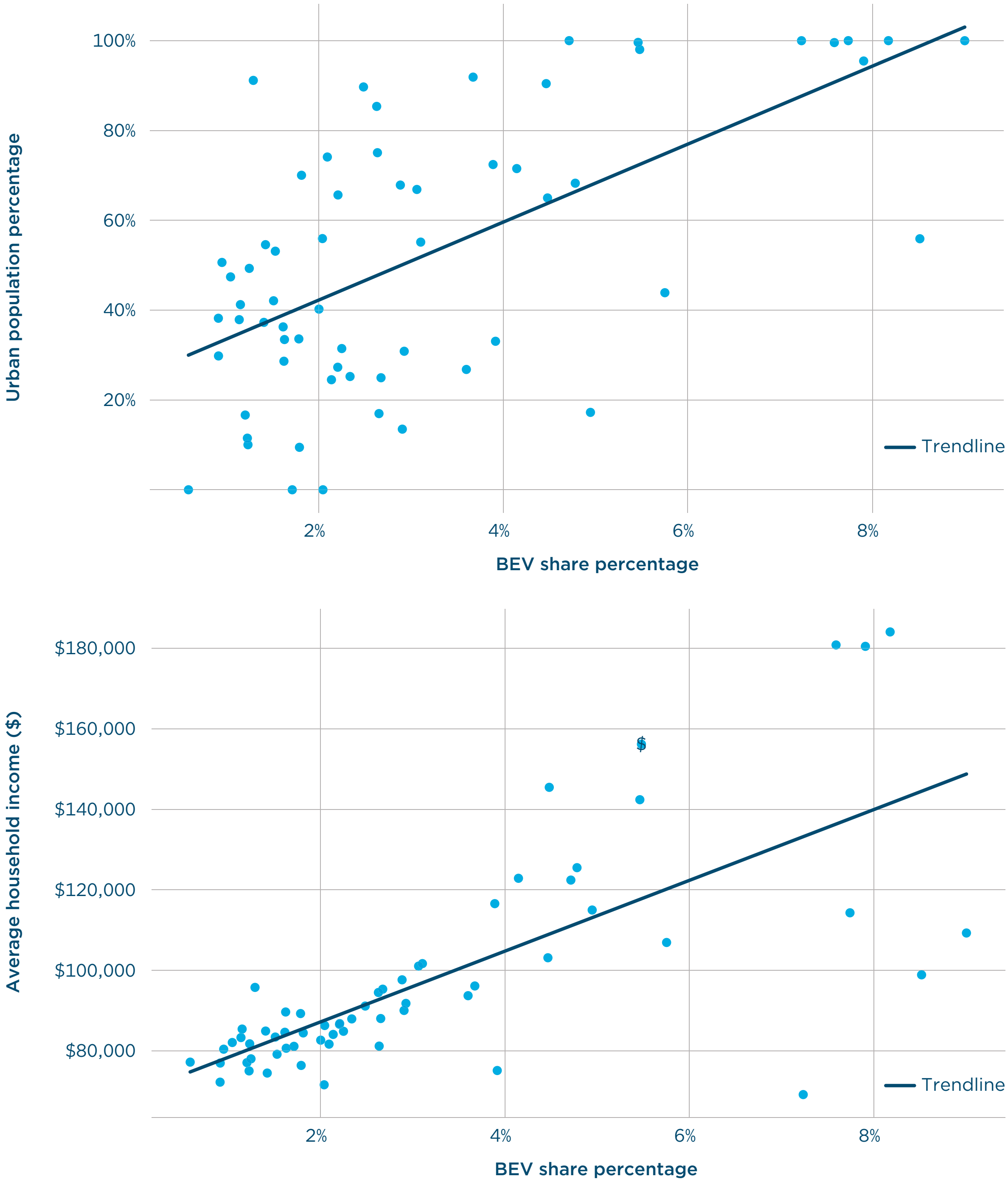


Figure 5. Statistically significant linear correlation found between battery electric vehicle share and urban population percentage (top panel) and average household income by county in New York (bottom panel)

In Figure 5, for the relationship between BEV share and urban population percentage, we see that counties are scattered around the trendline while still having an overall positive relationship. This indicates that counties with a higher BEV share tend to have a higher percentage of urban population, despite some variability. When looking at the relationship between BEV share and average household income in Figure 5, counties with a BEV share of 4% or below show close alignment with the trendline, and beyond a 4% BEV share, the data become more dispersed. This indicates greater variability in household income at higher levels of BEV adoption.

The statistical analysis of AC and DC public charging infrastructure per 10,000 capita found weak negative Pearson coefficients relative to BEV share (-0.03 and -0.26, respectively). For AC chargers, the p-value much greater than 0.05 indicates that the correlation is not statistically significant and can be discarded. For DC chargers, however, the p-value of 0.002 indicates statistical significance with BEV share, despite a weak and negative linear correlation. This might suggest that DC charging infrastructure per capita slightly decreases as BEV share increases in New York state. A potential explanation for this counterintuitive relation is that new BEV registrations in 2023 mostly occurred in urban counties with lower car ownership and lower vehicle-miles traveled (and therefore less energy demand on a per-capita basis), whereas most DC installations happened in intermediate and rural regions (Bureau of Transportation Statistics, 2024). Regardless, the weak Pearson correlation indicates DC charging points per 10,000 capita is not a significant factor associated with BEV share variations.

Case studies of rural regions with high BEV shares in new registrations

Rhön-Grabfeld

The rural region of Rhön-Grabfeld has historically been a leading region in terms of shares of BEVs in new passenger car registrations (Wappelhorst et al., 2022). The region is located in the state of Bavaria in the central part of Germany with a population of around 80,000 inhabitants in 2021 (Bayerisches Landesamt für Statistik, 2022). The region has a total area of 1,002 km^2 and a population density of around 80 inhabitants per km^2, roughly one-third of the national population density of 235 inhabitants per km^2. The 2022 gross income levels were lower than the German national average of €39,800 ($44,200) at €36,500 ($40,800) but slightly higher than the rural region average of €35,000 in the same year. The largest city in Rhön-Grabfeld is Bad Neustadt an der Saale, with around 15,000 inhabitants. In 2023, the total BEV registration shares, which include private individuals and company cars, stood at 25%, around 7 percentage points above the national BEV share average of 18%. A difference between BEVs registrations by private individuals and by companies is apparent here, as in 2023, company cars had a 21% share of BEVs (234 out of 1,132) and private individuals had a 32% share (242 out of 753). Access to AC public charging infrastructure was above the national average, with 6.9 points per 10,000 inhabitants in 2023. The DC number of charging points per 10,000 inhabitants in the same year was 0.6, lower than the national average of 0.8.

Rhön-Grabfeld has various local policies in place to promote BEV adoption. Rhön-Grabfeld benefits from the Bavaria-wide policy “Publicly accessible charging infrastructure for electric vehicles in Bavaria 2.0,” which started in November 2021 and expires in December 2025. It provides a maximum 60% of charge point installation costs, which is capped at €2,500 for AC chargers (< 22 kW) and €10,000 for DC chargers (>22kW – <100 kW) (Bayerisches Staatsministerium für Wirtschaft, Landesentwicklung und Energie, 2021). While this may account for the high BEV share within Rhön-Grabfeld, it is also available across Bavaria, and other factors may be influencing Rhön-Grabfeld’s performance on this metric.

From 2010 to 2016, Bad Neustadt an der Saale was the first Bavarian Model City for Electromobility funded by the Bavarian Ministry of Economics (Bad Neustadt, 2024). This project marked an important milestone in the start of research and development related to electromobility in the district, and it focused on establishing sustainable and competitive solutions and employment opportunities in the field. During this time, the city established an annual electric vehicle show to promote BEVs, and it continues to provide hands-on experience with new BEV models; the show ran for the eleventh time in 2024 (Rhön-Grabfeld, 2024b). The city and the district also host a joint webpage that provides information about the environmental, cost, noise, and savings benefits of BEVs, in addition to a cost calculator and links to related organizations, schools, universities, and institutions connected to electromobility in the district (Rhön-Grabfeld, 2024). In addition, Rhön-Grabfeld is home to auto manufacturing companies, including Siemens, where electric car components such as electric motors are produced. While it is not possible to measure the exact impact of these factors, they highlight the potential effect of awareness efforts on BEV adoption and possibly increased utilization of benefits from state or federal policies that may not be exclusively applicable to a region.

Columbia County

Columbia County is a rural county on the eastern edge of New York state bordering Massachusetts, south of the state capital Albany. With a population of 60,470 and an area of 1,678 km^2, its population density is 97 inhabitants per square mile. The county's mean household income of $114,994 is slightly below the state average but the highest among the state's rural regions. The county had a BEV share of 5%, which is just below the state average of 5.3% but higher than any other rural county in New York state and nearly twice the average among rural counties (2.7%). The county has 110 AC and 8 DC charging points, meaning that they have more AC and DC chargers on a per-capita basis than the statewide average. The largest city is Hudson, with a population of 5,894; no other towns in Columbia County have a population over 3,000 people.

Residents of Columbia County benefit from a variety of federal and state incentives, including the $7,500 federal tax rebate at point-of-purchase for select electric vehicle models (Internal Revenue Service, 2024) and the state's Drive Clean Rebate, which provides an additional $2,000 off the purchase price of 60+ BEV models (New York State Energy Research and Development Authority, 2024a). Additionally, the state's Charge Ready NY 2.0 program funds public and private organizations that install charging infrastructure points, with $4,000 per point installed at public facilities in disadvantaged communities and $2,000 per point installed at places of work or multi-unit dwellings (New York State Energy Research and Development Authority, 2024b).

There are several local efforts that distinguish the county from others in the state. Columbia County has an Alternative Fuel Infrastructure Task Force that works to secure locations for charging stations, accelerate their construction, and inform residents about the incentives for and benefits of ZEVs (Columbia County Climate Smart Communities Task Force, 2024). Both utilities that operate in the county, Central Hudson Gas and Electric and New York State Electric and Gas, have programs to encourage electric vehicle adoption: make-ready programs to reduce the cost of installing charging (both utilities); a fleet-assessment service for fleet owners who are considering electric vehicles (Central Hudson); and reduced rates for charging at home (both utilities). Central Hudson has also committed to 10% ZEVs in its fleet by 2025 and 50% by 2030.

Summary of factors associated with urban-rural disparities

Our analysis offers a complex picture of disparities in BEV adoption in rural and urban regions. There is evidence of a link between income and BEV adoption in rural areas, particularly in New York state, but other socio-economic and demographic factors may also play a role, as the case of eastern Germany indicates. Additionally, no clear links between public charging deployment and BEV share were found across urban and rural areas; instead, a broad pattern emerges of regions in eastern Germany and rural counties in upstate New York having above-average public charging availability but below-average BEV registration shares. Focusing on rural areas with above-average BEV shares may offer lessons that can be generalized, however. Initiatives by local authorities and institutions focused on awareness building, local business support, and siting infrastructure could explain the relative success in both the German district of Rhön-Grabfeld and Columbia County in state of New York.

Insights from battery electric vehicle user interviews

In this section, we present insights from semi-structured interviews conducted with 14 car users living in rural regions regarding the opportunities, challenges, and strategies for accelerating BEV adoption in rural regions. A summary of the approach and methodology adopted for conducting the interviews is provided in Appendix B. The majority of interviewees were based in the United States and Canada and were men, and the sample was evenly balanced in terms of the age profile of interviewees (Table 6). All but one of the interviewees were BEV owners and drivers at the time of the interview. These insights are based on a small sample, and subject to sampling bias. As such, they are intended only to ground-truth some of the assumptions about BEVs in rural regions and illustrate how the transition has unfolded for some rural drivers.

Table 6. Profile of the 14 interviewees

Characteristic	Interviewees
Location	United States: 6 (1 each in California, Colorado, Indiana, Massachusetts, Pennsylvania, and Virginia) Canada: 3 (2 in Québec and 1 in Ontario) Slovenia: 3 Northern Ireland (United Kingdom): 1 Ireland: 1
Age	26–40: 4 41–60: 4 61 and older: 6
Gender	Man: 11 Woman: 3
BEV ownership	Exclusively BEV owner: 8 Own both BEV and ICEV/hybrid: 5 ICEV owner likely to switch to BEV in near future: 1
BEV brands owned	Tesla: 6 Hyundai: 3 BMW: 1 GM (Chevrolet): 1 Škoda: 1 MG: 1

Motivations and experiences

The potential for savings in operational and maintenance costs was cited in the interviews as a key motivator of BEV adoption. Relatedly, avoiding frequent maintenance and trips to the gas station was also mentioned as a driver, as those often require round-trip journeys of 20 km or more. The desire to “do my bit for the environment” also featured, and some interviewees were technology enthusiasts for whom BEVs are an exciting new technology to experience.

I got out of the car at the end of a very long journey, and I just found I wasn't at all tired. And it felt very different to before and now, so I couldn't figure if it was the lack of noise. It was just such a quiet journey. It was really pleasant. Also . . . you don't carry your car, but it's a very lightweight vehicle. There was something . . . [that] felt very easy about the journey. It was very maneuverable.

—BMW i3 user in rural Ireland

The interviewees' experience of using a BEV was almost entirely positive, and performance characteristics like high acceleration and torque were often highlighted. For instance, some felt a lot more confident overtaking another vehicle on a narrow rural road with a BEV than with an ICEV. Ease of use was also valued. Some also said that BEVs are safer than ICEVs on narrow rural roads because their heavier bottoms (due to the battery) make it "practically impossible for the car to roll over" in a crash. More than half of the interviewees relied solely on their BEV(s) for transportation, an indicator of a strong degree of trust.

Charging and range anxiety

The ability to charge the car at home was the biggest enabler for switching to a BEV for all users.[4] Each stated they likely would not have purchased a BEV if they did not have the option to charge at home. More than 80% of electric vehicle users in the United States rely on home charging (U.S. Department of Transportation, 2024). Generally, when compared with cities, rural areas have a higher number of households with dedicated off-street parking such as a driveway or garage, which is ideal for installing home charging (McKinney et al., 2023).

Everybody focuses on the limitations of charging on long trips, but . . . with the gas car I had to go to a gas station once a week to fill up . . . [and] now we maybe use a public charger maybe five or six times a year. The rest of the time we're starting with a full tank in our driveway every morning and, if anything, that's more convenient for day-to-day usage.

—Chevy Bolt user in rural Québec, Canada

Regarding public charging, we found two sets of experiences. All Tesla users strongly approved of the supercharging network, and noted its availability, reliability, and speed of charging. One Tesla user from rural Slovenia shared that he once did a 1,100 km trip in a single day using the supercharging network and the total charging time was only about 40 minutes. Another Tesla user based in a rural area of the state of Massachusetts explained how he traveled from "New England to Florida four times and [it was] flawless. In all [that] time I had to maybe wait once or twice for 5 minutes to get a charging slot. The reliability is amazing!" Outside of the supercharging network, both Tesla and non-Tesla users shared concerns about the reliability (e.g., certainty that the charging point is working when one arrives at the station), availability (e.g., low density of charging network), inter-operability (e.g., charging connector compatibility with the car), and ease-of-use (e.g., availability of different forms of payment) of public charging stations. At the same time, multiple Tesla and non-Tesla users said they had made cross-country trips many thousand kilometers long without significant disruptions or incidents with charging.

4 Most interviewees were either retired or remote or freelance workers and office charging was not applicable or a relevant factor in their decision-making regarding choosing a BEV.

Interviewees reported no amount of range anxiety. Many stressed that unless someone is driving 200–300 miles every day, which is not necessarily common for rural users despite the perception, range anxiety is no longer an issue. They said that concerns about BEV range were rooted in outdated notions of battery capacity and availability of public charging that had not changed in line with material changes in those aspects in recent years.

Suitability of BEVs for rural regions

All interviewees said that BEVs were well suited for rural users and cited the ease of home charging and the performance characteristics that allows BEVs to perform better on mountainous or narrow rural roads than ICEVs. Indeed, noting the relative challenges associated with setting up home charging in urban areas, some users argued that BEVs are better suited for rural users than urban users.

Views were mixed on some issues often highlighted in literature. For instance, many users did not feel that a lack of diversity in BEV models for pick-up trucks was a significant barrier ("not everyone living in a rural region needs or uses a pick-up truck"). On the other hand, some said that pick-up trucks can be central to the rural economy and suggested that almost everyone living in a rural area has at some point done a job that required a pick-up truck. One user also pointed to how, if there were to be a wildfire, he would need a larger vehicle to carry belongings when leaving on short notice. Experiences with the towing capabilities of BEVs, an aspect noted by users as potentially more of a rural issue, were also mixed. Although one user who owned a Tesla Model X said he was surprised by how much his EV's range decreased while he was towing a small sailboat and felt that EVs are not currently well suited to carrying loads, another user who owned a Tesla Model Y viewed his EV as quite capable of towing small items.

> **To be honest, my only worry is the grid going down. I am not worried about the car not working. I am not worried about the charger not working. I'm worried if I leave the car with an empty battery and we have a power cut that lasts the whole night. . . . That is more of a concern at the minute.**
>
> —MG ZS driver in rural Northern Ireland, United Kingdom

Similarly, while most users did not have personal experience with power supply issues and their BEVs, many agreed that rural areas can be the last priority for sorting out power outages, which could pose a constraint for BEVs. Some users wished more BEVs came with power output capabilities that could help in times of power outage, as it could provide up to 100 kWh of backup power.

Power surges and voltage availability and stability were cited more frequently as an issue than outages. Grid suitability was also raised by several users, particularly those outside the United States and Canada. One rural BEV user from Slovenia commented how in some rural areas in the mountains, only 4–5 kW of electrical capacity is available for electric vehicle charging; the user noted, though, that this would likely be sufficient for overnight charging. Additionally, some users pointed out how rural homeowners may have more flexibility to install solar panels, and that could help reduce reliance on the grid and maximize the environmental and economic benefits of a BEV by further bringing down the emissions and operational costs.

Finally, one user highlighted the lack of familiarity with BEVs in terms of their repair and maintenance given that they are a new technology: "In a rural area, if you don't have any other vehicle, that could become an issue. Towing isn't that readily available in rural areas, either, in case something goes down. With gas vehicles, there is that implicit understanding that if something goes wrong, you can still somehow make it work. With [an] EV, if it goes down, that's it. You can't do much about it." Such situations may be mitigated by solutions like backup emergency charging services, and these may need to be scaled up or effectively advertised in different geographical contexts.

Supporting BEV adoption

Interviewees almost unanimously agreed that a lack of awareness around the suitability of BEVs in rural regions was impeding higher rates of adoption. They stressed the need to address notions and perceptions from non-users and BEV skeptics that may have been well-founded 5 years ago when BEV technology and charging networks were less mature but no longer reflect reality.

One user also said that BEVs have become "political in a way" and a few suggested that focusing on raising awareness of the performance, ease of use, and cost-effectiveness of BEVs may be helpful: "[if every electric vehicle skeptic] did a little bit of math on how much they spend on fuel through the course of a year, I think they would realize how much they have to gain from switching to an EV." Interviewees felt that governments could try to "make the calculation easy for users" by stressing cost savings, charging from home, and being able to use BEVs as a backup in case of power outages.

Some users touched upon affordability and upfront cost issues. The sole ICEV-only user interviewed cited high upfront cost as her barrier for switching to a BEV, and others suggested government incentive programs could offer loans with low interest rates for early years and provide support for setting up home charging. Upgrading electrical grids to enable fast charging or to ensure that electric vehicle charging demand does not exceed grid capacity were also noted as policy areas for improving rural BEV uptake. The interviewees suggested that government policies could emphasize increasing the availability of public charging in small towns, shopping areas, and workplaces, and that these stations do not necessarily have to be fast charging.

Summary

Interviewees affirmed a high level of satisfaction with their BEVs, which they explained are well suited for rural areas because of ease of home charging and certain performance characteristics like handling on narrow roads. One challenge highlighted was the adequacy of public charging infrastructure. This is aside from Tesla's superchargers, which the interviewees rated highly. However, the inadequacy was not cited as a deterrence from using their BEVs for long trips, nor does it make them reconsider their decision to use one. Power supply and grid-related issues may vary in intensity across geographies but was not commonly cited by the users we interviewed.

In terms of strategies, interviewees suggested that awareness building could help to accelerate BEV adoption in rural areas, as outdated notions around battery range and public charging availability may persist. Myth-busting aside, such awareness programs could focus on highlighting the ways in which BEVs perform better than ICEVs and the cost-saving potential of BEVs.

Some caveats are warranted. First, the modest sample of 14 interviewees limits the generalizability of the findings. Second, the limited geographical representation in the sample limits the ability to understand how issues surrounding things like power supply and public charging infrastructure vary across different regions. Finally, the entire sample consisted solely of current BEV users or those likely to use BEVs in the near future.

I think there's a lot of resistance to the idea amongst people just because it's change. And it's something new and so they're a little cautious, and that caution gets expressed as, "Ah, well, that can never work." or, you know, "I don't want to try that, gas is good enough for me." That sort of thing. But I think that the tide is slowly turning there. I think people are beginning to realize that there's a lot of cost savings. And it's not a terribly difficult hill to climb, it's just a different hill to climb, to make it work."

—Tesla user in rural Virginia, United States

These caveats notwithstanding, insights from the user interviews provide at least two fundamental points for policymakers. First, while affordability may remain a barrier within the rural population, there is likely to also be a distinct subset of rural ICEV users for whom affordability is not the defining issue. Here, a well-designed awareness-building campaign focused on the suitability of BEVs for rural users and their performance characteristics could be useful. Second, for those looking for insight into if BEVs work for rural users, the modest sample notwithstanding, the analysis in this study shows that they do.

Strategies for enabling higher battery electric vehicle adoption in rural regions

Based on the findings presented above, three strategic opportunities and challenges emerge. The first is affordability. In cases where rural areas are lagging urban areas in BEV adoption, financial incentives targeting rural residents could be considered. In Scotland, for instance, residents living in small towns, rural and remote areas, or islands are eligible for government-funded, interest-free loans to purchase a used electric car with a repayment period of up to 6 years (Energy Saving Trust, 2024). More broadly, incentive programs targeting lower-income and other socially disadvantaged populations, coupled with efforts to reduce information or other barriers to accessing these incentives, could ensure that cost is not a barrier for rural residents.

Second, for the rural car users for whom affordability may not be the defining issue or where other strategies such as public charging provision may not be sufficient, awareness-building campaigns could be helpful. A relevant example is the Rural Reimagined test drive program, which aims to increase EV awareness in rural Appalachia in Kentucky, Ohio, Tennessee, Virginia, and West Virginia by letting drivers borrow an EV for free for 2–6 weeks.[5]

Third, public charging infrastructure programs aimed at rural areas could help alleviate any remaining concerns about range anxiety. The Austrian government provides competitive tender funding, where selected proposals are awarded funds from the LADIN infrastructure program, which promotes the construction of public fast-charging infrastructure in "underserved areas" that do not have fast charging within a 7 km driving radius (Österreichische Forschungsförderungsgesellschaft, 2024).

In areas where EV charging infrastructure is lagging, developing appropriate information systems and institutional frameworks could help in closing the gaps. For example, Ladegrund is a tool designed to make possible sites for public charging more visible to investors and charging point

5 More information can be found at https://rural-reimagined.com/.

operators in Austria.[6] Austria has also set up a National Competence Center for Electromobility that, among many other functions, helps coordinate the expansion of charging infrastructure in way that is user-friendly, through a focus on payment methods, price transparency, or simplification of installation of private charging infrastructure (AustriaTech, 2022).

Effective planning for charging infrastructure deployment includes establishing forums for relevant stakeholders, such as municipal leaders, EV owners, grid operators, and charging infrastructure service providers, to share perspectives and identify funding opportunities. Charging infrastructure planning is also crucial to ensure that current and future electricity demand from EVs can be met. It will help anticipate any need to upgrade the electrical grid or to inform decisions for the installation of off-grid solutions to accommodate communities that are not connected to the central grid (U.S. Department of Transportation, 2023; Joint Office of Energy and Transport, 2024).

Appendix C provides an overview of the examples cited above and a wider list of strategies operational in different jurisdictions aimed at improving affordability, creating awareness, and developing public charging infrastructure for the ZEV transition in rural regions. A pattern we find among the strategies is the use of a wider "under-served" category as a focal point for the policies. Partly because there are rural regions with high rates of BEV uptake, a focus on under-served regions could enable policymakers to focus on rural areas that need special attention while ensuring other sections of society, such as individuals with disabilities or indigenous populations and tribes, are also covered within the scope of the policy. Moreover, factors associated with BEV uptake often go beyond the urban or rural nature of the region and potentially have roots in socio-economic, political, or demographic factors particular to the area. Finally, an approach grounded in broader equity concerns and promoting availability to a wider range of constituencies may also have higher chances of political approval.

Conclusions

The ZEV transition in rural regions is the subject of a growing body of research to which this study contributes. Our data and analysis offer insights into the presence of rural-urban disparities, potential reasons behind the disparities, and opportunities and challenges for BEV uptake in rural regions. It also identifies possible strategies for accelerating the ZEV transition.

We find that rural-urban disparities in terms of BEV registration shares vary between Germany and New York state. In Germany, rural regions are outperforming urban regions; 63% of rural regions have an above-average BEV registration share compared with only 56% of urban regions. In contrast, in New York state, rural counties are significantly underperforming in comparison with urban counties: no rural county has a BEV registration share above the state average and 36% of urban countries are performing above average. Moreover, urban-rural disparities may be associated with other geographic factors such as proximity to a large city in the case of New York state or historical regional divides in the case of eastern Germany.

Our analysis found varying patterns of association between income levels and public charging infrastructure with urban-rural disparities. For instance, while six out of seven rural regions in Germany with above-average income also have above-average BEV registration share, 63% of regions with below-average income also have an above-average share. Meanwhile, New York state

6 More information can be found at https://www. ladegrund.at/.

shows a high statistical correlation between income and BEV registration share at the county level. The number of public charging points (both AC and DC) per capita is above average for about 80% of rural regions in Germany, and that aligns well with 63% of rural regions having above-average BEV registration shares. However, 27% of rural German regions have an above-average number of AC charging points but below-average BEV registration shares. In New York state, where 50% of rural counties have an above-average number of AC charging points, no single rural county has an above-average BEV registration share.

Evidence from the interviews shows that rural BEV owners are highly satisfied with their experience of using a BEV. Ease of home charging combined with the performance of BEVs (e.g., higher acceleration) on rural roads were among the most valued aspects of BEV ownership cited by the interviewees. However, challenges remain in the form of affordability, public charging inadequacy, and power supply and grid issues.

Rural BEV owners emphasized in the interviews that lack of awareness is a key barrier to greater adoption. Awareness-building efforts that entail myth-busting but also focusing on the suitability of BEVs and their cost-saving potential could help to accelerate BEV uptake in rural regions. Test drive and car sharing programs that encourage users to borrow or rent a BEV for a short period for free or a minimal charge could be useful for this purpose. One example of such an effort is the Rural Reimagined test drive program focused on economically distressed communities in some U.S states in the Appalachian region.

Finally, policies can target a broad category of under-served regions that encompass rural regions. Such an approach could be used for strategies aimed at improving the affordability of BEVs, such as government-funded interest-free loans as provided in Scotland to residents living in small towns, rural and remote areas, or islands for purchasing a used electric car. Other policies could seek to improve the supply of public charging, such as LADIN in Austria, which promotes the construction of public fast charging infrastructure in “underserved areas” where there are no fast-charging stations within a 7 km driving radius. Awareness-building campaigns used in conjunction with such strategies could further help improve their effectiveness; our study found evidence of this dynamic in two rural regions of Germany and New York state with high BEV uptake.

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Appendix A. Definitions of urban and rural in select jurisdictions

Examples of definitions for urban and rural and other categories of regions (where applicable) used in the United States, European Union, Canada, and England is provided in Table A1. The definitions for the United States and European Union are the ones used in this study.

Table A1. Definitions of urban and rural used in this study

Jurisdiction	Definition of urban	Definition of rural	Definitions of other categories, if applicable	Source
United States	Contiguous set of census blocks with a minimum density of 425 housing units per square mile and a minimum population of 5,000 OR 2,000 housing units (there are considerable nuances and caveats associated with this basic definition)	All that is not urban		U.S. Census Bureau (2022; 2024a)
European Union	NUTS level 3 regions (those with a population between 150,000 and 800,000) are defined as “predominantly urban” if more than 80% of the population lives in urban clusters (a cluster of contiguous grid cells of 1 km^2 with a population density of at least 300 inhabitants per km^2 and a minimum population of 5,000 inhabitants)	NUTS level 3 regions are defined as “predominantly rural” if at least 50% of the population live in rural grid cells (those that are not identified as urban clusters or centers)	NUTS level 3 regions are defined as “intermediate regions” if more than 50% and up to 80% of the population lives in urban clusters	Eurostat (2018)
Canada	Minimum population concentration of 1,000 persons and a minimum population density of 400 persons per km^2	All that is not urban		Statistics Canada (2019)
England	Connected built up areas identified by Ordnance Survey mapping that have resident populations above 10,000 people	All that is not urban	The main categories of “urban” and “rural” have multiple sub-categories, including “urban with significant rural” and “largely rural.”	Office for National Statistics (2017)

Appendix B. User interviews – approach and methodology

Any person who self-identifies as living in a rural area and matches with one or more of the following attributes was considered a potential interviewee for the study:

- Owns and drives an electric car
- Is likely to buy an electric car in the next 3 years or so
- Is likely to buy a non-electric car in the next 3 years or so
- Has bought a non-electric car in the last few years

Our robust approach toward ensuring the data privacy of users who signed up to be interviewed or were indeed interviewed for the study was detailed in a document that included the steps taken to obtain consent from interviewees and protocols regarding storage, access to, and use of their personal and interview data. Based on this document, clearance was obtained from an internal ICCT committee set up for reviewing research-related data privacy issues.

For recruitment, advertisements about the study with links to a sign-up form and a study information sheet were shared on the Facebook pages of various EV user associations in the United States, Canada and Europe. Various EV user associations were also contacted over email with a request to share the study details with their members. In addition, the ad was disseminated through the social media accounts (LinkedIn and X) of the ICCT with the social media handles of EV user associations tagged. All users who signed up and fit the attributes were interviewed.

The interviews were semi-structured. We asked questions related to broad themes and left room for the interviewees to explore the issues they felt were important. The themes included their residential (e.g., location, density of community, distance from nearest big town, etc.) and travel characteristics (e.g., typical frequencies for trips out of home, average trip lengths, modes used for travel, etc.), attitudes toward and status of BEV ownership, experience of using BEVs, charging arrangements and experiences, views on suitability of BEVs in rural areas, and opinions on the utility of e-bikes and e-scooters in rural areas. The interviews were conducted virtually over MS Teams and Zoom. They typically lasted between 30 and 60 minutes and Otter AI was used for transcribing the interviews.

Thematic analysis, a method for identifying, analyzing, and reporting patterns or themes within qualitative data (Braun & Clarke, 2006; Braun & Clarke, 2022), was used for analyzing the interview data. We created a codebook using the software program NVIVO Pro version 12.6.0 and it contained various thematic nodes that either aligned with the questions or interesting insights that came out of the interviews. Different parts of the interview transcripts were coded against these nodes and thereafter various insights were drawn based on patterns of interview data emerging from various themes.

Appendix C. Overview of strategies for accelerating rural battery electric vehicle adoption

The following strategies were found through a literature review of prevailing practices that are aimed at positively influencing the uptake of BEVs in rural areas.

Table C1. Strategies for accelerating rural battery electric vehicle adopt

Strategic focus	Policy measure	Description	Target group	Jurisdiction	Status and period	Source
Improving affordability	Interest-free loans depending on income and size of residence	Loan for the purchase of a used electric car with a price of up to $32,000 (£25,000); repayment over a period of up to 6 years	Individuals with an annual household income of no more than $64,000 (£50,000) or residents living in small towns, rural and remote areas or islands in Scotland	Scotland, United Kingdom	Status: Ongoing Period: Since August 2024	Energy Saving Trust (2024)
	Subsidy depending on personal mobility restrictions or size of residence (MOVES III Program)	Up to $7,700 (€7,000) for the purchase/ leasing of a new electric vehicle (BEV, PHEV, FCEV); increase in the maximum funding amount by 10 per cent (not cumulative) for groups of people mentioned under 'Target group'	Private individuals with disabilities and reduced mobility, private individuals registered in municipalities with fewer than 5,000 inhabitants, self-employed taxi and transport companies	Spain	Status: Ongoing Period: 2023 until 2024	Instituto para la Diversificación y Ahorro de la Energía (2024)
Developing public charging infrastructure and grid upgradation	Grants/financial schemes to improve access to public charging infrastructure	Competitive tender for fast-charging deployment	Focus on so called "underserved areas" that do not have fast charging within 7km or more	Austria	Program ran between October 2023 and March 2024 (construction of winning projects starting in September 2024 and is ongoing)	Die Österreichische Forschungsförderungsgesellschaft (2024)
		Support scheme for public DC fast charging	Specific tender requirements for density of chargers, distance between chargers, off-grid areas, and mountain passes	Norway	Light-duty: Closed in 2022 Heavy-duty: Ongoing	Ministry of Transport (2023)
		$15 million for the installation of normal and fast charging infrastructure – under the Charging fuel infrastructure program (CFI program)	New York state officials responsible for sites which include state parks, hotels, tourist destinations, state office buildings, municipal car parks, small to medium sized towns classified as disadvantaged with a high proportion of multi-family housing	New York, United States	Status: Ongoing Period: Since January 2024	New York State Energy Research and Development Authority (2024c)
		$1.3 billion in funding for charging and fueling infrastructure (CFI)	States or political subdivisions of States, metropolitan planning organizations, unit of local governments, Indian Tribes, etc. in urban and rural areas alike	United States	Status: Ongoing Period: Since 2022	Federal Highway Administration (2024a)
		National Electric Vehicle Program - State program for the deployment of EV fast chargers along strategic highways referred to as "EV corridors".	Under Justice 40: 40% of benefits need to be felt in underserved communities	United States	Status: Ongoing (5 years program)	(Patterson, Boyd, Khatib, Taylor, Balik, Marpillero-Colomina, & Francis, 2023; Federal Highway Administration, (2024b)
	Charging infrastructure targets	In the 'National electric vehicle charging strategy for Aotearoa New Zealand 2023-2035', the government set the target to install at least 600 charging station in rural areas by 2028	Rural areas	New Zealand	Status: Ongoing	New Zealand Government (2024)
	Toolkits and playbooks	The U.S Department of Transportation has developed a one stop resource to help rural communities and relevant stakeholders' scope, plan and fund charging infrastructure and to ensure the grid is EV friendly and to deploy off grid solution in most remote areas.	Rural entities including States, local communities, Tribes, transportation providers, nonprofits, businesses, and individuals	United States	Status: Ongoing Period: since 2023	U.S. Department of Transportation (2023)
		The U.S Joint Office of Energy and Transport has developed a playbook to help communities plan and build charging infrastructure	The playbook is addressed to Communities, planning organizations, local and state governments, tribal nations among other decision makers	United States	Status: Ongoing	Joint Office of Energy and Transportation (2024)
		LocationTOOL: Planning tool to support the expansion and planning of public charging infrastructure	Municipal planning officers and network operators, charging infrastructure operators, interested public participants	Germany	Status: Ongoing Period: since 2018	Nationale Leitstelle Ladeinfrastruktur (2024).
		Ladegrund: a tool designed to make unused spaces more visible	Investors and charging point operators	Austria	Status: Ongoing	Ladegrund, (https://www.ladegrund.at/)
	Developing appropriate institutional frameworks	National Competence Center for Electromobility: Helps coordinate the expansion of public charging infrastructure in way that is fair and user-friendly for everyone	Municipalities	Austria	Status: Ongoing	(AustriaTech, 2022)
Creating awareness	Test drive and car sharing programs	The Rural Reimagined test drive program aims to increase EV awareness by letting users borrow an EV free of charge for 2-6 weeks	Focus on the most economical distressed communities within the Appalachian rural regions in in Kentucky, Ohio, Tennessee, Virginia, and West Virginia states	Kentucky, Ohio, Tennessee, Virginia, and West Virginia states	Status: Ongoing	Rural Reimagined (https://rural-reimagined.com/)
		Míocar is an example of a community EV carsharing program that allows residents to experience EVs through an affordable rental rate	Focus on low income and underserved rural areas	California, United State	Status: Ongoing	(Míocar, 2024)
		Affordable electric vehicle car-sharing program introduced in both urban and rural areas of East Tyrol to promote sustainable transportation options	Flugs covers the entire region, including rural mountainous areas.	East Tyrol & Upper Carinthia, Austria	Status: Ongoing (introduced in 2015)	(Euromontana, 2020; Regionalenergie Osttirol, 2024)
	Initiative to raise awareness about zero-emission vehicles	Financial support for projects aimed at increasing awareness, knowledge and confidence in zero-emission vehicles in all vehicle classes	Indigenous communities, government organizations and for-profit/non-profit companies/ organizations that demonstrate that indigenous groups are leading the projects	Canada	Status: Ongoing Period: 2024 to 2025	Natural Resources Canada (2024)

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