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***Rebound Effects for shifting to Electric Vehicles in Nordic
Households***

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Contents

Abstract	4
Introduction	6
1. Literature Review	10
1.1 Rebound concepts: from energy-service demand to environmental outcomes	10
1.2 Direct rebound in conventional road transport	12
1.3 Electric vehicles and travel demand: an emerging and conflicting literature	13
1.3.1 Why EV rebound estimates disagree	15
1.4 Household carbon footprints, indirect rebound, and consumption trade-offs	16
1.5 Heterogeneity: income, household structure, vehicle fleets, and settlement type	18
1.6 Climate concern, environmental attitudes, and mobility behaviour	19
1.7 Why the Nordic context is analytically important	21
1.8 Synthesis of the empirical evidence	22
1.9 Research gap and hypotheses	25
2. Materials and Methods	27
2.1 Data source: the 1.5 Degree Lifestyles Nordic survey	27
2.2 Consumption-based carbon-footprint accounting	28
2.3 Analytical sample and comparison groups	29
2.4 Variables	30
2.5 Empirical strategy	32
2.6 Research design, internal validity, and interpretation	34
2.6.1 Reproducibility and reporting	35
3. Results	36
3.1 EV ownership and annual vehicle-kilometres travelled per capita	36
3.2 EV ownership and total consumption-based carbon footprint	38
3.3 Heterogeneity by climate concern	40
3.4 Spatial heterogeneity in the EV-VKT association	42
3.5 Summary of hypotheses	45
4. Discussion	46
4.1 RQ1 and H1: no evidence of a positive direct driving rebound	46
4.2 RQ2 and H2: lower total carbon footprint and the role of indirect or desirable rebound	48

4.3 RQ3 and H3: climate concern changes the pattern, but not in the originally expected direction.....	50
4.4 RQ4 and H4: strong spatial differences in mobility, but no significant EV-by-settlement interaction.....	52
4.5 Contribution to the rebound literature	54
4.6 Policy implications	55
4.7 Methodological limitations.....	56
4.8 Suggestions for future research	58
5. Conclusion.....	61
References	63

Abstract

Electric vehicles (EVs) are a central component of transport decarbonisation, yet their environmental performance depends not only on vehicle technology but also on household behaviour. Lower operating costs can reduce the marginal price of mobility and may therefore stimulate additional travel, partly offsetting expected energy and emission savings. This behavioural response is commonly discussed as a rebound effect. The present thesis examines whether patterns consistent with a direct usage rebound are observable among car-owning households in Denmark, Finland, Iceland, Norway, and Sweden, and whether the relationship between EV ownership and driving differs by climate concern and degree of urbanisation. It also evaluates whether EV ownership is associated with differences in total consumption-based carbon footprint per capita, thereby placing mobility behaviour within a broader household-consumption perspective.

The analysis uses harmonised household microdata from the 1.5 Degree Lifestyles project. Multivariable regressions compare households owning at least one battery electric vehicle (BEV) with non-EV car-owning households while controlling for income, household size, settlement type, and country. The main outcome for direct usage rebound is annual vehicle-kilometres travelled (VKT) per capita. Total consumption-based carbon footprint per capita is analysed as a broader environmental outcome. Climate concern is examined through separate high- and low-concern subsamples, while spatial heterogeneity is evaluated using interaction terms between EV ownership and degree of urbanisation.

The results do not support a positive direct driving rebound in the observed Nordic sample. EV ownership is associated with a coefficient of -0.1197 in the log-VKT model ($p = 0.003$), corresponding to approximately 11.3% lower VKT per capita than among comparable non-EV car-owning households. EV ownership is also associated with a coefficient of -0.2309 in the total-carbon-footprint model ($p < 0.001$), corresponding to approximately 20.6% lower carbon footprint per capita. Climate-concern subgroup results are heterogeneous: the EV coefficient is negative and significant in the low-concern group but close to zero and statistically insignificant in the high-concern group. This difference should not be interpreted as causal moderation because the analysis uses cross-sectional data and does not formally test equality of subgroup coefficients. Rural and town/suburban households drive more than city households, but EV-by-settlement interaction terms are not statistically significant.

The findings show that a positive direct rebound is not an inevitable correlate of EV ownership in a mature, relatively low-carbon electricity context. At the same time, the cross-sectional design cannot identify the causal effect of switching from an internal-combustion vehicle to an EV, and total carbon-footprint differences may partly reflect selection, lifestyle, fleet composition, and budget allocation. The thesis therefore contributes to rebound research by combining mobility, household carbon footprints, environmental attitudes, and settlement context in a multi-country Nordic setting, while emphasising the need for longitudinal and consumption-category-specific research to distinguish direct, indirect, and potentially environmentally beneficial forms of rebound.

Keywords: electric vehicles; rebound effect; vehicle-kilometres travelled; household carbon footprint; climate concern; urbanisation; Nordic countries; consumption-based accounting.

Introduction

Electrification of passenger transport is a major climate-mitigation strategy because battery electric vehicles eliminate tailpipe emissions and can reduce life-cycle greenhouse-gas emissions relative to internal-combustion vehicles when they are powered by sufficiently low-carbon electricity (Hawkins et al., 2013; Coffman et al., 2017). The size of this advantage depends on factors such as the electricity mix, vehicle and battery production, lifetime mileage, and the type of vehicle being replaced. For this reason, the environmental effect of electrification cannot be assessed from powertrain technology alone; household use and wider consumption also matter (Coffman et al., 2017; Font Vivanco et al., 2014, 2022).

A central behavioural mechanism is the change in the effective price of mobility. Rebound theory predicts that when an energy service becomes cheaper to use, demand for that service may increase (Sorrell and Dimitropoulos, 2008; Gillingham et al., 2016). For EVs, lower energy and maintenance costs per kilometre can reduce the marginal monetary cost of driving. Additional travel would then offset part of the expected technical saving. Savings can also be spent in other consumption categories, creating an indirect rebound through the household budget (Hertwich, 2005; Font Vivanco et al., 2022).

The conventional road-transport literature supports this mechanism, but it does not point to one universal rebound rate. Dimitropoulos et al. (2018) show in their meta-analysis that estimates vary with the time horizon and empirical design, while household-level studies also identify differences by income and baseline mileage (Fronzel et al., 2012; Andersson et al., 2019). Short-run responses are generally smaller because households have less opportunity to change vehicles, residential location, commuting patterns, or discretionary travel. The conventional evidence is therefore a useful benchmark for EVs, not a rebound percentage that can simply be transferred to a different technology.

EV adoption differs from a marginal improvement in fuel economy because several things change at once: propulsion technology, purchase cost, charging routines, range, and sometimes the composition of the household vehicle fleet (Rezvani et al., 2015; Hardman et al., 2018; Haustein et al., 2021). EV adopters also differ systematically from non-adopters in socioeconomic characteristics, environmental attitudes, access to charging, and travel requirements. This creates a selection problem for cross-sectional comparisons. An observed

EV/non-EV difference in VKT therefore cannot, by itself, be interpreted as the causal effect of switching powertrains (Ojeda-Diaz et al., 2025; Zhang et al., 2026).

For that reason, the EV-specific evidence is mixed. Reviews by Ojeda-Diaz et al. (2025) and Zhang et al. (2026) show that studies use different outcomes, comparison groups, adoption stages, and identification strategies. Norwegian travel-survey evidence, for example, finds additional car demand and substitution from other modes after BEV ownership (Green and Ostli, 2025). By contrast, other studies report no positive BEV effect on VKT or lower mileage for BEVs than for gasoline vehicles (Zhao et al., 2023; Zhang et al., 2025). The disagreement is therefore substantive, but part of it also reflects what each study is actually measuring.

The Nordic countries provide a useful setting for examining these questions because EV diffusion is advanced, yet policy histories, settlement patterns, and the geography of electric mobility differ across the region (Kester et al., 2018, 2020). Electricity systems are also relatively low-carbon in international comparison, although the generation mix differs between countries (Heinonen et al., 2022). These national and spatial differences are relevant to both EV adoption and travel demand, which is why country and degree of urbanisation are included explicitly in the empirical analysis (Næss, 2012).

Transport behaviour also needs to be placed within the rest of household consumption. Nordic consumption-based studies show that household carbon footprints are closely related to affluence and consumption level and that lower emissions in one domain can coexist with higher emissions elsewhere (Heinonen et al., 2022). Ottelin et al. (2024) show this specifically for mobility: differences in total carbon footprints between car-free households, minimal drivers, and green-car owners become smaller once broader consumption patterns are considered. This motivates analysing total consumption-based carbon footprint alongside VKT rather than assuming that all rebound appears as additional driving (Hertwich, 2005; Font Vivanco et al., 2022).

Rebound is also likely to differ across households because mobility needs and opportunities are not the same everywhere. Previous work identifies heterogeneity by income, baseline travel and household circumstances (Fronzel et al., 2012; Font Vivanco et al., 2022). In low-density and rural areas, longer distances and weaker access to services or alternative modes often lead to higher baseline car use (Næss, 2012; Stjernborg and Lopez Svensson, 2024). That does not necessarily imply stronger rebound, however, if much of the travel is already necessary. In

Nordic conditions, winter range and charging performance can add another constraint to discretionary EV use (Delos Reyes et al., 2016; Motoaki et al., 2018).

Environmental attitudes provide another possible source of heterogeneity. Environmental-behaviour research links values, beliefs, norms and perceived control to pro-environmental action, but also shows that the relationship is far from deterministic (Stern, 2000; Bamberg and Moser, 2007). The attitude-behaviour gap is particularly relevant here: strong concern can coexist with carbon-intensive behaviour when infrastructure, habits, income, time or convenience limit the available choices (Kollmuss and Agyeman, 2002; Steg and Vlek, 2009; Gifford, 2011; Moser and Kleinhuckelkotten, 2018). At the same time, Nordic household evidence finds an association between higher climate concern and lower consumption-based carbon footprints, which provides a clear reason to examine climate concern in this study (Árnadóttir et al., 2024).

Against this background, this thesis examines whether EV ownership among car-owning Nordic households is associated with a pattern consistent with a direct usage rebound and how that relationship fits within a broader consumption-based climate perspective. The analysis uses harmonised household microdata from the 1.5 Degree Lifestyles project for Denmark, Finland, Iceland, Norway, and Sweden (University of Iceland, 2024). Annual VKT per capita is the main behavioural outcome, while total consumption-based carbon footprint per capita is used as the broader climate outcome. Income, household size, settlement type, and country form the baseline control set; climate concern and degree of urbanisation are then examined as sources of heterogeneity.

One terminology point is important from the outset. In the rebound literature, a formal direct rebound effect is defined relative to a counterfactual change in efficiency or effective service price and is commonly expressed as an elasticity or as the share of expected savings taken back by additional service use (Sorrell and Dimitropoulos, 2008; Gillingham et al., 2016). The present data do not follow the same household before and after an EV switch, so they cannot identify that causal elasticity. Here, a positive conditional EV-VKT association is treated only as evidence consistent with the predicted direct-usage mechanism; a zero or negative association provides no support for a positive direct driving rebound in this sample (Ojeda-Diaz et al., 2025; Zhang et al., 2026).

The thesis addresses four research questions:

RQ1. Among car-owning Nordic households, is EV ownership associated with annual vehicle-kilometres travelled per capita after controlling for income, household size, settlement type, and country?

RQ2. Among car-owning Nordic households, is EV ownership associated with total consumption-based carbon footprint per capita after controlling for the same socioeconomic and spatial factors?

RQ3. How does the association between EV ownership and vehicle-kilometres travelled compare between households with low and high climate concern?

RQ4. Does the association between EV ownership and vehicle-kilometres travelled differ across cities, towns and suburbs, and rural areas?

These questions deliberately distinguish an average conditional association (RQ1 and RQ2) from heterogeneity analyses (RQ3 and RQ4). They also align directly with the four empirical sections of the Results and Discussion chapters. The contribution of the study is threefold. First, it extends EV rebound research to harmonised household data covering five Nordic countries rather than a single national market. Second, it combines a mobility-service outcome with a consumption-based carbon-footprint outcome, allowing direct usage patterns to be interpreted within a wider household budget. Third, it brings climate concern and settlement type into the empirical framework as potential sources of heterogeneity rather than assuming a single rebound response for all households.

The remainder of the thesis is organised as follows. Chapter 1 reviews rebound theory, empirical evidence from conventional road transport and electric vehicles, consumption-wide and indirect rebound mechanisms, household heterogeneity, and the role of climate concern. It concludes by synthesising the literature, defining the research gap, and deriving four hypotheses. Chapter 2 describes the Nordic household dataset, the construction of EV ownership, VKT, carbon-footprint, climate-concern, and control variables, and the regression strategy. Chapter 3 reports the empirical results for the four hypotheses. Chapter 4 interprets the findings in relation to the literature, discusses policy implications and methodological limitations, and develops suggestions for future research. Chapter 5 concludes by answering the research questions without extending the claims beyond what the cross-sectional data support.

1. Literature Review

The review is organised around the questions that matter for the empirical. It begins with the rebound concept and the distinction between direct, indirect, economy-wide and environmental rebound. It then examines what is known about travel-demand responses, why EV studies reach different conclusions, how wider household consumption changes the environmental interpretation, and how household, attitudinal and spatial factors may create heterogeneity. The aim is to establish where the literature agrees, where it remains uncertain, and how those points lead to the four hypotheses tested later in the thesis.

1.1 Rebound concepts: from energy-service demand to environmental outcomes

Rebound research starts from a simple economic mechanism: if an efficiency improvement lowers the effective cost of an energy service, behavioural and market responses can reduce part of the saving that would have occurred if service demand had remained unchanged. Greening et al. (2000), Sorrell and Dimitropoulos (2008), and Gillingham et al. (2016) use this logic to distinguish direct, indirect and broader market responses. The distinction matters because each mechanism occurs through a different part of the consumption system and requires a different empirical approach.

Direct rebound occurs within the improved service itself. In private transport, it is usually observed as additional travel after fuel or energy cost per kilometre falls. Sorrell and Dimitropoulos (2008) emphasise that its formal measurement is counterfactual: actual energy use after behavioural adjustment must be compared with the saving expected if kilometres had remained fixed. A cross-sectional EV/non-EV mileage difference is therefore related to this mechanism, but it is not a conventional rebound elasticity because pre-adoption driving cost and within-household change are not observed (Ojeda-Diaz et al., 2025; Zhang et al., 2026).

Indirect rebound moves the response outside the improved service. Hertwich (2005) explains that savings from lower energy expenditure can be re-spent on other goods and services, so the environmental outcome depends on both the amount saved and the environmental intensity of what is purchased instead. Later rebound work develops the same household-budget mechanism in more detail (Sorrell and Dimitropoulos, 2008; Font Vivanco et al., 2022). Once the question shifts from transport alone to total environmental performance, the relevant accounting boundary is therefore the wider household budget rather than fuel use only.

Economy-wide rebound is broader again. It includes market responses through prices, production, productivity, investment and economic activity rather than only household re-spending (Greening et al., 2000; Brockway et al., 2021). These channels require macroeconomic or economy-wide modelling and are outside the scope of the household microdata used here. The thesis therefore limits its claims to household mobility and consumption-based carbon footprints.

Industrial ecology adds an environmental perspective to the same problem. Hertwich (2005) argues that changes in consumption can shift burdens between products, sectors and life-cycle stages, meaning that an energy rebound and a greenhouse-gas rebound do not have to be identical. Font Vivanco et al. (2014, 2022) extend this reasoning to electric cars and sustainability more broadly. Their work makes two points especially relevant here: the environmental indicator must be stated clearly, and rebound should not be reduced to one technology-specific percentage without specifying the counterfactual and system boundary.

EVs make this accounting issue particularly visible. Life-cycle studies show that electrification changes not only direct fossil-fuel use but also electricity demand and embodied vehicle impacts (Hawkins et al., 2013; Font Vivanco et al., 2014). At household level, lower operating expenditure can free money for other consumption, while a relatively high vehicle purchase cost can constrain other spending. Depending on what is added or displaced, the budget response can either erode or reinforce the climate saving (Font Vivanco et al., 2022; Ottelin et al., 2024). The wider household effect is therefore something to be examined, not assumed.

The environmental outcome used in this thesis is narrower than a full multi-impact life-cycle assessment. It is the consumption-based carbon footprint expressed in greenhouse-gas emissions. The empirical conclusions therefore concern climate change, not biodiversity, toxicity, land use, water use, or mineral-resource impacts. This boundary follows the Nordic household-footprint framework used in the source dataset, which allocates supply-chain greenhouse-gas emissions to final consumption (Heinonen et al., 2022; University of Iceland, 2024).

This framework leads to three practical choices. VKT is used to examine whether household mobility follows the direction predicted by a direct usage rebound. Total consumption-based carbon footprint is used to see whether the broader household climate difference remains once non-transport consumption is included. Because the data are cross-sectional, both are interpreted as conditional associations rather than causal rebound elasticities.

1.2 Direct rebound in conventional road transport

The conventional road-transport literature provides the clearest empirical basis for direct rebound because fuel cost, efficiency and vehicle travel can be linked within a familiar demand framework. Studies estimate the response using changes in fuel price, fuel efficiency or effective cost per kilometre, but the underlying question is the same: how much additional mobility is induced when a kilometre becomes cheaper to provide (Small and Van Dender, 2007; Sorrell and Dimitropoulos, 2008; Gillingham et al., 2016).

The main point of agreement is the direction of the response, not its size. Dimitropoulos et al. (2018) find in their meta-analysis that direct road-transport rebound is generally positive and tends to be larger over longer time horizons. Their interpretation is intuitive: households can adjust vehicle ownership, residential location, commuting arrangements and discretionary travel more easily over time. Household-level evidence from the United States, Germany and Sweden also shows that rebound varies substantially between periods and populations (Small and Van Dender, 2007; Frondel et al., 2012; Andersson et al., 2019).

Heterogeneity is therefore a recurring result rather than an exception. Frondel et al. (2012) and Su (2012), for example, show that baseline mileage and the position of a household within the travel-demand distribution matter for the response to lower operating cost. Income matters as well because the same monetary saving represents different budget relief for different households. Swedish evidence reports comparatively modest average rebound, which also suggests that institutional and socioeconomic context shapes the observed response (Andersson et al., 2019).

Methodological choices add another source of variation. Sorrell and Dimitropoulos (2008) distinguish carefully between fuel-price responses, efficiency responses and changes in effective service price, while Greene (2012) and Dimitropoulos et al. (2018) show how estimates can change with the travel measure, treatment of endogenous efficiency and time horizon. Numerical rebound estimates are therefore meaningful only when the estimand and counterfactual are clear.

This evidence cannot be transferred mechanically to EVs. EV adoption is a discrete technology and ownership change rather than a small improvement in the fuel economy of an otherwise similar vehicle. Reviews of EV adoption show that the decision also involves purchase price, range, charging, vehicle attributes and user preferences (Rezvani et al., 2015; Zhang et al., 2026). In multi-car households, the relevant behavioural response can include substitution between

vehicles and between transport modes, not simply more kilometres in one car (Tamor and Milacic, 2015; Jensen and Mabit, 2017; Green and Ostli, 2025).

The broader cost of travel also matters. Nordic EV policy has affected purchase prices, taxation and road-use privileges, while charging availability shapes convenience and time cost (Kester et al., 2018; Hardman et al., 2018). Congestion, parking, travel time and range uncertainty remain even when energy per kilometre becomes cheaper. For EVs, monetary operating cost is therefore only one part of the generalised cost of mobility.

The conventional literature supports a qualified expectation for H1. Cheaper driving can generate additional travel, but the size of the response depends on household circumstances, time horizon and what is actually measured. That makes a positive EV-VKT association theoretically plausible without making it inevitable in every setting (Dimitropoulos et al., 2018).

1.3 Electric vehicles and travel demand: an emerging and conflicting literature

The EV literature is easier to understand when it is organised around mechanisms rather than around apparently contradictory results. Reviews identify several recurring influences: lower operating cost, charging and range, allocation of trips within the household fleet, modal substitution, adopter selection, market maturity and policy context (Ojeda-Diaz et al., 2025; Zhang et al., 2026). These mechanisms can push observed travel in different directions, which explains why studies do not converge on one EV rebound estimate.

One part of the evidence concerns the realised travel response. Green and Ostli (2025) find that BEV ownership in Norway is associated with greater car-trip demand and substitution from other modes. Other studies point in a different direction: Zhao et al. (2023) report lower average BEV mileage in the United States, while Zhang et al. (2025) find no positive BEV effect on VKT or trip frequency in Dutch travel-survey data. These results are not directly interchangeable because they use different outcomes and counterfactuals, but together they show that lower operating cost does not lead to the same observed behaviour in every context.

Charging and range repeatedly appear as practical limits on EV use. Hardman et al. (2018) review evidence showing that home and workplace charging are important for usability, while Tal et al. (2014) and Langbroek et al. (2017) show that charging routines are closely tied to realised electric-vehicle use. Range matters in a similar way: Zhao et al. (2023) find that the mileage gap between BEVs and gasoline vehicles narrows as electric driving range increases.

Vehicle capability therefore affects both how an EV is used and which households are willing to adopt it.

Household fleet composition creates another important distinction. Studies of multi-vehicle households show that an EV can take over kilometres from another household car without increasing total household VKT (Tamor and Milacic, 2015; Jensen and Mabit, 2017). Modal substitution adds a second layer because some additional car use may come from public transport or other modes rather than from entirely new travel (Green and Ostli, 2025). This is why vehicle mileage, household VKT and mode share answer related but different questions.

Selection into EV ownership is equally important. Reviews and Nordic adoption studies associate EV choice with income, environmental attitudes, technology perceptions, charging access, range expectations and geographical setting (Rezvani et al., 2015; Westin et al., 2018; Haustein et al., 2021). A cross-sectional EV coefficient therefore reflects both behaviour after adoption and the characteristics of the households that chose the technology in the first place. Without pre-adoption travel, these two components cannot be separated cleanly.

The composition of adopters also changes as the market matures. Early EV markets tend to favour households whose parking, charging access, environmental motivation and travel patterns fit the available vehicles. As range improves and charging expands, EVs become feasible for a wider set of users. The range-related mileage evidence reported by Zhao et al. (2023), together with recent reviews, supports the idea that observed EV use can change as both the technology and the adopter population evolve (Ojeda-Diaz et al., 2025; Zhang et al., 2026).

Taken together, these findings show why neither high EV mileage nor low EV mileage has a single interpretation. A high-mileage EV may simply be replacing kilometres previously driven by another car, while low observed mileage may reflect range constraints or selection rather than a behavioural reduction caused by adoption. Reviews of the field therefore stress the importance of stating the unit of analysis and the counterfactual before drawing conclusions about rebound (Ojeda-Diaz et al., 2025; Zhang et al., 2026).

The Nordic setting adds meaningful variation in policy and market maturity. Kester et al. (2018, 2020) describe how Nordic EV uptake developed through different combinations of purchase incentives, tax treatment, road-use benefits and charging provision. Norway reached mass-market adoption earlier than its neighbours, while the other countries followed different trajectories. This

variation matters because the effective advantage of EV ownership, and the type of household adopting an EV, can differ across countries and over time.

The sign of the EV-VKT association should therefore remain an empirical question. A positive conditional coefficient would be consistent with the classical operating-cost mechanism; a coefficient near zero would mean that no additional household travel is detected; and a negative coefficient would suggest that selection, fleet allocation, technological constraints or mobility structure dominate the simple price mechanism in the observed cross-section. None of these outcomes, on its own, identifies the within-household causal effect of switching to an EV (Ojeda-Diaz et al., 2025; Zhang et al., 2026).

1.3.1 Why EV rebound estimates disagree

The first reason EV studies can appear to disagree is that they do not always measure the same thing. Reviews distinguish vehicle mileage, household VKT, trip frequency, mode share, energy use and total environmental impact as separate outcomes (Ojeda-Diaz et al., 2025; Zhang et al., 2026). A multi-car household, for example, can increase the mileage of its EV by reallocating trips from another vehicle while leaving total household VKT almost unchanged (Tamor and Milacic, 2015; Jensen and Mabit, 2017).

Trip frequency and distance also need to be separated. Lower operating cost may create more short trips without much change in annual kilometres, or longer trips without a large increase in trip counts. Zhang et al. (2025) illustrate this distinction in Dutch travel data. Green and Ostli (2025) add a further complication by showing that car demand can increase through substitution from other modes. Studies using different mobility outcomes can therefore reach different conclusions without necessarily contradicting one another.

A second source of disagreement is the counterfactual. Sorrell and Dimitropoulos (2008) distinguish marginal price or efficiency responses from simple cross-sectional differences, while Font Vivanco et al. (2014) show how life-cycle environmental rebound uses a different technical baseline again. EV-versus-ICE comparisons, before-and-after adoption studies, price-elasticity models and life-cycle assessments therefore estimate related but different quantities. Their numerical results should not be compared without considering the denominator, time period and level of analysis (Ojeda-Diaz et al., 2025; Zhang et al., 2026).

Adopter composition and market maturity create another difference between studies. Early adopters are more likely to be shaped by charging access, range requirements, environmental motivation, technology interest and socioeconomic resources (Rezvani et al., 2015; Haustein et al., 2021). As the technology improves, later adopters can include households with different travel needs. Zhao et al. (2023) provide one concrete example: the mileage gap between BEVs and gasoline vehicles narrows as electric driving range increases.

Policy context also changes the effective cost of mobility. Nordic EV policy has combined purchase incentives, tax exemptions, toll treatment, road privileges and charging investment in different ways across countries and periods (Holtmark and Skonhoft, 2014; Bjerkan et al., 2016; Kester et al., 2018). At the same time, congestion, parking scarcity, travel time and charging constraints remain part of the cost of using a car (Hardman et al., 2018). National context is therefore part of the behavioural mechanism, not merely a statistical control.

For these reasons, the literature is more useful when it is synthesised around mechanisms and estimands than when it is reduced to one 'EV rebound percentage'. The current reviews reach a cautious conclusion: lower operating cost creates a plausible incentive for additional travel, but the observed response depends on what is measured, the household fleet, charging and range, adopter selection, modal alternatives, market maturity and policy context (Ojeda-Diaz et al., 2025; Zhang et al., 2026). This is the rationale for using household-level outcomes and explicit heterogeneity tests in the present study.

1.4 Household carbon footprints, indirect rebound, and consumption trade-offs

A VKT model captures only the mobility-service channel. Indirect rebound concerns what happens to the rest of the household budget when mobility expenditure changes. Hertwich (2005) and Sorrell and Dimitropoulos (2008) describe how savings can be redirected to other consumption categories, while Font Vivanco et al. (2022) emphasise that the environmental effect depends on what those categories are. The relevant climate question is therefore not only whether fuel emissions fall, but whether the total household footprint remains lower after non-transport consumption is included.

Consumption-based accounting provides the broader boundary needed for that question. It attributes supply-chain emissions to the final consumer regardless of where production occurs (Ivanova et al., 2016). Environmentally extended multi-region input-output models capture emissions embodied in domestic and imported goods and services, while hybrid approaches can

combine that broad coverage with process-specific life-cycle data for activities measured in physical units (Stadler et al., 2018; Heinonen et al., 2022). This is particularly useful in affluent economies with large international supply chains.

Nordic household research consistently shows that affluence and consumption volume are major drivers of greenhouse-gas footprints. Nassen et al. (2015) and Heinonen et al. (2022) both find strong socioeconomic patterns, while Barros and Wilk (2021) illustrate how high-income consumption can produce very large footprints. Household structure and urban form also matter because shared consumption, accessibility and mobility systems affect per-capita outcomes (Ottelin et al., 2019).

The mobility literature shows why these wider effects matter. Ottelin et al. (2024) compare car-free households, minimal drivers and green-car owners in the Nordic region. Their results show that differences in transport emissions become smaller when socioeconomic characteristics and the rest of household consumption are considered. The point is not that mobility choices have no effect, but that a transport-only indicator can overstate the size of the final household-level climate difference.

The budget effect can also work in either direction. Font Vivanco et al. (2022) discuss how lower operating expenditure can free resources for other consumption, which would erode part of the saving, while a relatively expensive low-carbon purchase can crowd out expenditure elsewhere. If the displaced consumption is carbon-intensive, the net household effect can become more favourable. This beneficial or 'desirable' rebound-like pathway is plausible, but it has to be demonstrated rather than assumed; Nordic evidence on cross-domain consumption trade-offs makes it relevant to consider here (Ottelin et al., 2024).

The total-footprint regression used in this thesis can observe the net association in which these budget responses are embedded, because the outcome includes the wider consumption basket. It cannot trace a causal spending chain, such as a particular fuel saving being used for a particular flight, nor can it identify whether EV purchase expenditure displaced another category. That would require longitudinal expenditure data, category-level footprints and information on vehicle purchase timing (Font Vivanco et al., 2022; Ottelin et al., 2024).

This is the key distinction behind H2. A lower total carbon footprint among EV-owning households would show that wider consumption does not fully erase their conditional footprint advantage in this sample. It would not explain why the difference exists. A null result would also

remain compatible with several mechanisms, including indirect rebound, adopter selection, housing differences or other unobserved lifestyle characteristics (Hertwich, 2005; Ottelin et al., 2024).

1.5 Heterogeneity: income, household structure, vehicle fleets, and settlement type

Rebound is heterogeneous because both price sensitivity and the practical opportunity to consume more mobility differ between households. Frondel et al. (2012) document this clearly for conventional transport, and recent EV reviews reach the same broader conclusion (Font Vivanco et al., 2022; Zhang et al., 2026). Income, baseline travel, household composition, vehicle-fleet configuration, time constraints, charging access, alternative modes and settlement structure can all change the observed response. Average coefficients can therefore hide important subgroup differences.

Income can work in opposite directions. Small and Van Dender (2007) show that fuel-cost sensitivity can decline as income rises because operating savings form a smaller share of a high-income household's budget. At the same time, higher-income households generally have greater mobility and purchasing capacity and are better positioned to adopt new vehicle technologies. Lower-income households may be more responsive to running-cost reductions but face larger barriers to EV purchase (Rezvani et al., 2015; Haustein et al., 2021). Income is therefore both a possible source of rebound heterogeneity and an important confounder in an observational EV comparison.

Household composition matters because mobility and consumption contain shared components. Research on household footprints shows that larger households can have lower per-capita emissions because dwellings, vehicles, appliances and some journeys are shared (Nassen et al., 2015; Heinonen et al., 2022). The same logic makes negative household-size coefficients plausible for per-capita VKT even if total household kilometres are higher. Keeping the unit of the dependent variable explicit is therefore essential when household-size effects are interpreted.

Vehicle-fleet composition creates a different behavioural margin. In a one-car household, replacing an ICE vehicle with an EV exposes nearly all private-car travel to the new operating cost. In a multi-car household, trips can be allocated according to range, charging access, passenger needs and trip length. Studies of multi-vehicle households show that EV mileage can rise through substitution within the fleet without increasing total household VKT (Tamor and Milacic, 2015; Bjornsson and Karlsson, 2017; Jensen and Mabit, 2017). The EV indicator used

here is therefore interpreted as the presence of EV technology in the household, not as an all-electric fleet.

Settlement structure affects both baseline mobility and the scope for behavioural adjustment. Nordic urban-form and rural-mobility research links density, centrality and accessibility to travel demand and shows that rural areas often face longer distances and fewer alternatives to the private car (Næss, 2012; Stjernborg and Lopez Svensson, 2024). Higher rural VKT is therefore expected as a baseline pattern. The rebound question is different: does the EV/non-EV gap itself change across settlement types?

There are reasons to expect either a stronger or a weaker rural response. Long distances increase the value of cheaper EV kilometres and could make extra travel more attractive. On the other hand, a large share of rural travel may already be necessary for work, education, healthcare or shopping, leaving little discretionary margin to expand (Næss, 2012; Stjernborg and Lopez Svensson, 2024). Cold-weather range loss and slower fast charging can add a further constraint to long-distance EV use (Delos Reyes et al., 2016; Motoaki et al., 2018).

Settlement type can also shape who is able to adopt an EV. Home charging, private parking, charging-network coverage, range and local policy support are not distributed evenly across space (Hardman et al., 2018; Kester et al., 2020; Haustein et al., 2021). Degree of urbanisation therefore serves two roles in the analysis: it is a baseline control for structural mobility differences and, through interaction terms, a test of whether the conditional EV-VKT association itself changes by place.

1.6 Climate concern, environmental attitudes, and mobility behaviour

Economic rebound models focus mainly on price and efficiency, whereas environmental-behaviour research shows that values, norms, habits, perceived consequences and contextual constraints also affect action (Stern, 2000; Steg and Vlek, 2009). Climate concern is relevant here because it may influence both the decision to adopt an EV and mobility after adoption. If this pathway is ignored, part of an apparent technology effect may actually reflect the environmental preferences of the households that selected the technology (Rezvani et al., 2015; Árnadóttir et al., 2024).

The value-belief-norm tradition provides one theoretical basis for expecting environmental attitudes to matter. Stern (2000) argues that values and beliefs can activate personal norms and

increase the likelihood of environmentally significant behaviour. Bamberg and Moser (2007) reach a similar conclusion in a meta-analysis of psychosocial determinants, while also showing that effect sizes differ between behaviours and contexts. Climate concern is therefore a meaningful behavioural variable, but not a mechanical predictor of low emissions or low VKT.

The attitude-behaviour gap is an important qualification. Kollmuss and Agyeman (2002) and Steg and Vlek (2009) review the many reasons environmental concern does not always translate into high-impact action, including habits, convenience, infrastructure and limited behavioural control. Gifford (2011) adds psychological barriers, while Moser and Kleinhuckelkotten (2018) show that pro-environmental self-identity can coexist with large carbon footprints when affluent lifestyles support high consumption. Climate concern should therefore be treated as one influence among several.

For EVs, adopting a lower-emission vehicle and reducing mobility are separate choices. A household may switch technology while keeping roughly the same level of car travel, whereas reducing VKT can require changes in commuting, service access, mode choice or household routines. Behavioural research on high-impact actions supports this distinction (Steg and Vlek, 2009; Wynes and Nicholas, 2017). EV adoption itself is also influenced by cost, range, charging, technology perceptions and environmental motivation, so attitudes can affect the composition of the EV-owning group (Rezvani et al., 2015; Haustein et al., 2021).

Nordic household evidence gives this argument direct empirical relevance. Árnadóttir et al. (2024) find that higher climate concern is associated with lower consumption-based carbon footprints even after socioeconomic characteristics are taken into account. Olson et al. (2024) further show that people differ in the pro-climate actions they are willing to undertake. These findings support the inclusion of climate concern, while also cautioning against treating stated concern as equivalent to any one specific behaviour.

Climate concern may also interact with technological constraints through selection. One possible mechanism is that high-mileage drivers with little environmental motivation were historically less willing to accept limited range or charging inconvenience, leaving lower-mileage households overrepresented among low-concern EV adopters. Adoption research makes this mechanism plausible, and Zhao et al. (2023) show that realised BEV mileage changes with vehicle range (Rezvani et al., 2015; Haustein et al., 2021). The present data do not contain pre-adoption mileage, so this remains a possible explanation rather than a finding.

H3 is therefore framed as a heterogeneity test rather than a directional hypothesis that high concern must reduce rebound. The analysis compares the EV coefficient in low- and high-concern subsamples. Because a coefficient being significant in one group and not significant in another does not establish a statistically significant difference between the groups, the subgroup results are interpreted cautiously (Gelman and Stern, 2006). A pooled interaction using the original five-point concern scale would provide a stronger test and would avoid the information loss that comes with dichotomisation (MacCallum et al., 2002).

1.7 Why the Nordic context is analytically important

The Nordic countries are not treated here simply as a convenient geographical group. They combine advanced EV diffusion, relatively high incomes, comparatively low-carbon electricity and meaningful variation in transport systems, settlement structure and policy development (Kester et al., 2018, 2020; Heinonen et al., 2022). That combination makes the region useful for studying rebound at an advanced stage of the EV transition while still retaining differences across countries and places.

Electricity context changes the climate consequence of additional EV travel. Hawkins et al. (2013) show that the life-cycle greenhouse-gas advantage of an EV depends strongly on the carbon intensity of the electricity used in operation. Nordic electricity systems generally include large shares of hydropower, wind, nuclear power and other low-carbon sources, although the mix differs across countries (Heinonen et al., 2022). A given increase in EV VKT can therefore have a different greenhouse-gas consequence in the Nordic region than in a more fossil-intensive electricity system.

Income creates another reason to examine the Nordic context carefully. Conventional rebound work suggests that fuel-cost sensitivity can weaken as income rises, because fuel expenditure represents a smaller share of the household budget (Small and Van Dender, 2007). At the same time, affluent households have more scope for carbon-intensive consumption in other domains. Nordic footprint research therefore makes indirect and cross-domain effects especially relevant alongside the direct VKT response (Heinonen et al., 2022; Ottelin et al., 2024).

The countries also differ in the maturity and design of EV policy. Norway developed a mass market earlier through a long combination of tax advantages, toll benefits and charging support, while Denmark, Finland, Iceland and Sweden followed different policy trajectories (Holtmark and Skonhoft, 2014; Bjerkan et al., 2016; Kester et al., 2018). Country fixed effects cannot

identify the impact of any one policy, but they reduce the risk that one national context is treated as representative of the whole Nordic region.

Spatial variation is equally important. Nordic urban-form research shows that accessibility and settlement structure shape travel demand, while rural households can face long distances to employment and essential services (Næss, 2012; Stjernborg and Lopez Svensson, 2024). EV infrastructure and adoption also have a spatial dimension (Kester et al., 2020). In addition, long distances and cold conditions can make range and charging reliability more important for some households (Delos Reyes et al., 2016; Motoaki et al., 2018).

A further advantage of the Nordic case is the existing consumption-based carbon-footprint literature. Research in the region links household demand to emissions across domestic and international supply chains and shows that transport outcomes are connected to affluence, housing, goods, services and leisure consumption (Ivanova et al., 2016; Heinonen et al., 2022; Ottelin et al., 2019, 2024). This provides a useful bridge between the transport-demand perspective used for H1 and the wider industrial-ecology perspective used for H2.

These same features also limit external validity. High incomes, mature institutions, advanced EV policy and relatively low-carbon electricity mean that Nordic findings should not automatically be transferred to regions with different electricity mixes, charging systems, settlement patterns or stages of EV diffusion (Hawkins et al., 2013; Kester et al., 2020; Zhang et al., 2026). The region is therefore treated as a strategically informative case, not as a universal transport system.

1.8 Synthesis of the empirical evidence

Table 1 summarises the key empirical studies, but the argument developed in this chapter remains thematic. Across the literature, five issues repeatedly explain why results differ: the cost-response mechanism, the outcome and unit of analysis, charging and range constraints, household and adopter selection, and the wider consumption boundary (Ojeda-Diaz et al., 2025; Zhang et al., 2026).

Table 1. Synthesis of literature relevant to EV rebound, travel demand, and household carbon footprints

Study / setting	Design	Outcome	Main relevant finding	Relevance / limitation
Small & Van Dender (2007)	US conventional cars; econometric panel	VKT / fuel efficiency	Positive but declining rebound as income rises	Benchmark for direct road-transport rebound; not EV-specific.
Fronzel et al. (2012)	German household microdata	Mileage / fuel price	Rebound heterogeneous by baseline mileage	Shows household-level heterogeneity.
Dimitropoulos et al. (2018)	Meta-analysis of road-transport studies	Short- and long-run rebound	Short-run effects smaller than long-run effects	Strong synthesis; estimates depend on method.
Andersson et al. (2019)	Swedish microdata	Car use / fuel efficiency	Relatively modest Swedish rebound estimates	Directly relevant Nordic conventional-car evidence.
Greene (2012)	US light-duty vehicle statistics	Travel / fuel economy	Positive rebound with specification sensitivity	Illustrates dependence on empirical design.
Su (2012)	US household travel survey	Quantile regression of VKT	Rebound varies across travel-demand distribution	Supports heterogeneous responses.
Tal et al. (2014)	US plug-in vehicle users	EV miles / charging	Charging behaviour associated with EV mileage	Highlights charging access as use constraint.
Klößner et al. (2013)	Norwegian EV adopters	Purchase and car use	Adoption and use linked to psychological factors	Selection into EV ownership matters.
Jensen & Mabit (2017)	Danish households adding an EV	Household vehicle use	EV changes allocation of trips within household fleet	Vehicle-level mileage differs from household VKT.
Langbroek et al. (2017)	EV users; stated adaptation	Charging timing / adaptation	Charging embedded in daily travel routines	Behavioural mechanisms beyond energy efficiency.
Vassileva & Campillo (2017)	Swedish early adopters	Adoption barriers / experience	Cost, charging and range shape EV use	Relevant to Nordic adopter selection.
Hardman et al. (2018)	Review of charging-infrastructure research	Charging preferences	Home/work charging strongly shapes usability	Infrastructure conditions behavioural response.
Bjornsson & Karlsson (2017)	Two-car household modelling	PHEV vs BEV utilisation	Fleet configuration affects electric kilometres	Motivates household fleet heterogeneity.
Tamor & Milacic (2015)	Multi-vehicle households	Vehicle allocation	Household fleet strongly affects EV utilisation	Cautions against single-vehicle counterfactual.
Jia & Chen (2022)	US households with zero-emission vehicles	Vehicle miles travelled	EV mileage patterns depend on other household vehicles	Direct EV-usage evidence.
Zhao et al. (2023)	US BEVs and gasoline vehicles	Annual mileage / vehicle range	BEVs driven less on average; gap narrows with range	Range and market maturity important.
Zhang et al. (2025)	Dutch national travel survey	Trip frequency and VKT	No evidence of positive BEV rebound in VKT	European evidence against universal positive

				rebound.
Green & Ostli (2025)	Norwegian travel survey	Car trips / mode substitution	BEV ownership increases car-trip demand and shifts modes	High-quality evidence of positive behavioural response.
Ojeda-Diaz et al. (2025)	Scoping review	Rebound and spillover outcomes	Results vary widely with outcome and counterfactual	Shows lack of consensus and comparability problem.
Font Vivanco et al. (2014)	Life-cycle model of electric cars	Environmental rebound	Environmental rebound can differ from energy rebound	Broadens analysis beyond direct energy use.
Heinonen et al. (2022)	Nordic household carbon footprints	Consumption-based CF	High footprints driven by consumption level and intensities	Establishes Nordic whole-consumption context.
Ottelin et al. (2024)	Nordic mobility groups	Total household CF	Consumption trade-offs flatten mobility-group differences	Key evidence for indirect/budget rebound.
Arnadottir et al. (2024)	Nordic households	Climate concern / CF	Higher concern associated with lower total footprint	Motivates attitudinal heterogeneity.
Nassen et al. (2015)	Household GHG emissions	Socioeconomic and motivational factors	Income, household and motivation explain footprint variation	Supports combined structural/attitudinal controls.
Olson et al. (2024)	Nordic demand-side options	Household CF	Low-carbon options have heterogeneous footprint effects	Supports consumption-wide policy interpretation.

Note. Studies use different rebound definitions and counterfactuals; numerical estimates should not be compared without considering the outcome and unit of analysis (Ojeda-Diaz et al., 2025; Zhang et al., 2026).

The evidence points to several reasonably clear conclusions. Conventional road transport supports a positive cost-response mechanism, although its magnitude varies by time horizon, income, baseline travel and empirical method (Fronzel et al., 2012; Dimitropoulos et al., 2018). EV-specific studies are less uniform because lower operating cost interacts with range, charging, fleet allocation, modal substitution, adopter selection and market maturity (Green and Ostli, 2025; Zhao et al., 2023; Zhang et al., 2025, 2026). Consumption-based work adds a further qualification: transport savings can be weakened or reinforced by what happens elsewhere in the household budget, while attitudes and settlement structure shape both technology choice and baseline mobility (Árnadóttir et al., 2024; Ottelin et al., 2024; Kester et al., 2020).

The literature therefore supports neither the claim that EV rebound is inevitably large nor the claim that electrification is behaviourally neutral. Recent reviews make clear that vehicle mileage, household VKT, modal substitution and total carbon footprint use different counterfactuals and should not be treated as interchangeable measures (Ojeda-Diaz et al., 2025; Zhang et al., 2026). The present thesis responds to that problem by analysing household-level VKT and total consumption-based carbon footprint in one harmonised Nordic dataset, with climate concern and settlement type examined as explicit sources of heterogeneity.

1.9 Research gap and hypotheses

The first gap is geographical and comparative. Most of the EV rebound and EV-use evidence comes from single-country studies, while recent reviews show substantial context dependence across countries, methods and adoption stages (Ojeda-Diaz et al., 2025; Zhang et al., 2026). A harmonised five-country Nordic analysis offers a way to examine the EV-VKT association across a region with broadly similar institutions but meaningful differences in policy maturity, geography and the spatial pattern of EV adoption (Kester et al., 2020).

The second gap concerns environmental scope. Many EV rebound studies focus on vehicle travel, trip frequency, energy use or operational emissions. Sustainability-oriented rebound research argues that these outcomes are incomplete if changes elsewhere in household consumption are ignored (Font Vivanco et al., 2022). Nordic evidence confirms that mobility-related carbon differences can be altered by the wider consumption basket (Ottelin et al., 2024). Combining VKT with total consumption-based carbon footprint therefore connects the direct behavioural mechanism with a broader household climate outcome.

The third gap concerns environmental attitudes. Climate concern is well established in research on pro-environmental behaviour and is associated with Nordic household carbon footprints, but it is less often integrated directly into quantitative EV rebound models (Stern, 2000; Árnadóttir et al., 2024; Ojeda-Diaz et al., 2025). Because concern can influence both EV adoption and mobility after adoption, the direction of the relationship is not obvious. H3 is therefore framed as a heterogeneity question rather than treating climate concern as a standard baseline control.

The fourth gap is spatial. Nordic research shows large baseline differences in car dependence and accessibility, and EV adoption and infrastructure also vary by place (Næss, 2012; Kester et al., 2020; Stjernborg and Lopez Svensson, 2024). What is less clear is whether the EV/non-EV VKT contrast itself changes across cities, towns/suburbs and rural areas. H4 addresses that question with interaction terms so that baseline rural VKT is not confused with spatial heterogeneity in the EV association.

The four hypotheses are defined to correspond exactly to the research questions and empirical tests:

H1 - Direct car-use rebound hypothesis. Conditional on income, household size, settlement type, and country, EV-owning households are expected to have higher annual VKT per capita than non-EV car-owning households. This directional prediction follows the direct rebound

mechanism whereby lower effective driving cost can increase mobility demand (Sorrell and Dimitropoulos, 2008; Dimitropoulos et al., 2018). A positive EV coefficient would provide evidence consistent with that mechanism; a zero or negative coefficient would not support H1.

H2 - Total carbon-footprint hypothesis. Conditional on income, household size, settlement type, and country, EV-owning households are expected to have a lower total consumption-based carbon footprint per capita than non-EV car-owning households. The prediction is informed by the lower operational greenhouse-gas potential of EVs in low-carbon electricity contexts and by evidence that broader household consumption can attenuate, but does not necessarily eliminate, mobility-related footprint differences (Hawkins et al., 2013; Ottelin et al., 2024). H2 concerns the net footprint outcome and is not a direct estimate of indirect rebound.

H3 - Climate-concern heterogeneity hypothesis. The association between EV ownership and VKT is expected to differ between low- and high-climate-concern households. Environmental concern is related to environmentally significant behaviour and Nordic carbon footprints, while adoption research indicates that attitudes can also influence who selects an EV (Stern, 2000; Rezvani et al., 2015; Árnadóttir et al., 2024). Because these pathways can operate in competing directions, H3 is intentionally non-directional.

H4 - Spatial-heterogeneity hypothesis. The association between EV ownership and VKT is expected to differ across cities, towns and suburbs, and rural areas. Urban form and rural accessibility generate strong differences in baseline mobility, while EV adoption and use are also conditioned by charging, range, and spatial infrastructure (Næss, 2012; Kester et al., 2020; Stjernborg and Lopez Svensson, 2024). H4 is therefore tested with EV-by-settlement interaction terms rather than with the main effect of settlement type alone.

These hypotheses create a one-to-one analytical chain. H1 tests the direct-rebound direction with VKT, H2 tests the broader consumption-based carbon footprint, H3 tests attitudinal heterogeneity in the EV-VKT association, and H4 tests spatial heterogeneity in the same association. The same outcome definitions, comparator group, control set, and inferential limits are carried through the Methods, Results, Discussion, and Conclusion chapters.

2. Materials and Methods

This chapter describes the data source, environmental accounting framework, analytical sample, variable construction, and regression strategy. The methodological structure follows the research questions closely: each research question is linked to one outcome, one empirical test, and one interpretation. The study is observational and cross-sectional. Consequently, regression coefficients are interpreted as conditional associations rather than causal effects of switching to an EV.

2.1 Data source: the 1.5 Degree Lifestyles Nordic survey

The empirical analysis uses household microdata from the 1.5 Degree Lifestyles project, a harmonised survey of consumption and carbon footprints in Denmark, Finland, Iceland, Norway and Sweden. According to the dataset documentation, data collection took place from autumn 2021 to spring 2022 using online recruitment, including social-media advertising, and eligible respondents were adults who lived in one of the five countries and took part in household financial decisions (University of Iceland, 2024). Heinonen et al. (2022) describe the broader survey design, which collected detailed physical and behavioural information on household consumption rather than relying only on expenditure aggregates.

The survey contains socioeconomic variables, dwelling and household characteristics, climate attitudes, travel and vehicle information, and consumption-based carbon-footprint estimates. For private cars, respondents reported the vehicles available to the household, fuel or powertrain type, and annual distance driven during the previous 12 months. Battery electric vehicles are identified as a separate technology category, and the harmonised construction allows common variables to be analysed across the five countries (University of Iceland, 2024).

The number of observations differs across the analyses because the thesis imposes study-specific restrictions. The principal comparison is between EV-owning and non-EV car-owning households, so car-free households are excluded from the main regressions. Further observations can be unavailable because of missing values in the outcome or covariates, and the climate-concern subgroup analysis excludes midpoint responses by construction. For this reason, the analytical sample is defined by the variables required for each specification rather than by one headline survey count. Model-specific sample sizes should accompany the regression estimates

because the climate-concern restriction and item-level missingness can change the estimation sample across models.

The cross-sectional design provides broad coverage of household differences but does not observe the same household before and after EV adoption. This limitation matters because EV adopters differ systematically from non-adopters in attitudes, charging access, socioeconomic characteristics, and travel requirements (Rezvani et al., 2015; Westin et al., 2018; Haustein et al., 2021). The analysis therefore estimates conditional associations between current EV ownership and outcomes rather than the within-household treatment effect of adoption. Unobserved pre-adoption mileage, charging access, vehicle preferences, and long-distance travel needs can still contribute to the estimated EV coefficient.

2.2 Consumption-based carbon-footprint accounting

The carbon-footprint variables in the 1.5 Degree Lifestyles project use consumption-based accounting, which assigns greenhouse-gas emissions to final consumption rather than to the territory where production occurs. This boundary includes supply-chain emissions embodied in imported as well as domestically produced goods and services (Ivanova et al., 2016; Heinonen et al., 2022).

The footprint model combines activity-specific life-cycle information with environmentally extended multi-region input-output data. Heinonen et al. (2022) describe how process-based data are used for major consumption activities where physical quantities are available, while remaining goods and services are covered through input-output emission intensities. EXIOBASE provides the multi-region input-output component and allows supply-chain emissions across countries and sectors to be represented consistently (Stadler et al., 2018; University of Iceland, 2024).

The environmental outcome used in this thesis is greenhouse-gas emissions expressed as a consumption-based carbon footprint per capita. Although the accounting framework is rooted in life-cycle assessment and industrial ecology, the present analysis does not evaluate multiple impact categories. It evaluates climate change only. This distinction matters for interpretation because a reduction in carbon footprint should not be presented as evidence of lower environmental impact across toxicity, resource use, land use, biodiversity, or other categories (Hawkins et al., 2013; Font Vivanco et al., 2014).

The source survey calculates private-vehicle emissions from reported distance and vehicle or fuel information together with the corresponding energy and emission factors. For EVs, electricity consumption follows the assumptions used in the source footprint model. The total carbon-footprint outcome extends beyond private-car operation and includes greenhouse-gas emissions associated with the respondent's wider consumption basket (University of Iceland, 2024; Heinonen et al., 2022). It is therefore the appropriate outcome for RQ2.

This broader outcome is useful for rebound analysis because re-spending can shift emissions from transport into other consumption categories. Hertwich (2005) and Font Vivanco et al. (2022) describe this household-budget pathway: lower running costs can release resources for other purchases, while a high vehicle purchase cost can constrain expenditure elsewhere. Ottelin et al. (2024) show why such cross-domain trade-offs matter in Nordic household footprints. The cross-sectional total can therefore capture the net footprint associated with the wider consumption basket, but it cannot trace the direction of money flows or identify a causal indirect-rebound pathway. That would require longitudinal or category-specific budget data.

2.3 Analytical sample and comparison groups

The unit of analysis is the household/respondent record in the harmonised survey. The principal explanatory variable is EV ownership, coded as 1 when the household reports at least one battery electric vehicle and 0 when it owns one or more cars but no battery electric vehicle.

Car-free households are excluded from the main EV versus non-EV comparison. Including households with no car would mechanically introduce a large group with zero private-car VKT and would answer a different policy question: car ownership versus non-ownership rather than EV technology versus other car ownership. The reference group throughout the thesis is therefore described consistently as "non-EV car-owning households" rather than the ambiguous term "non-EV owners".

Vehicle-distance reports are aggregated across household vehicles and normalised by household size in the source construction used for this analysis (University of Iceland, 2024). The VKT outcome is therefore interpreted consistently as annual vehicle-kilometres travelled per capita. Maintaining this unit throughout the thesis is essential because the same household-size coefficient has a different substantive meaning for per-capita VKT than for total household VKT.

2.4 Variables

Table 2 summarises the variables used in the empirical models.

Table 2. Variables used in the empirical analysis

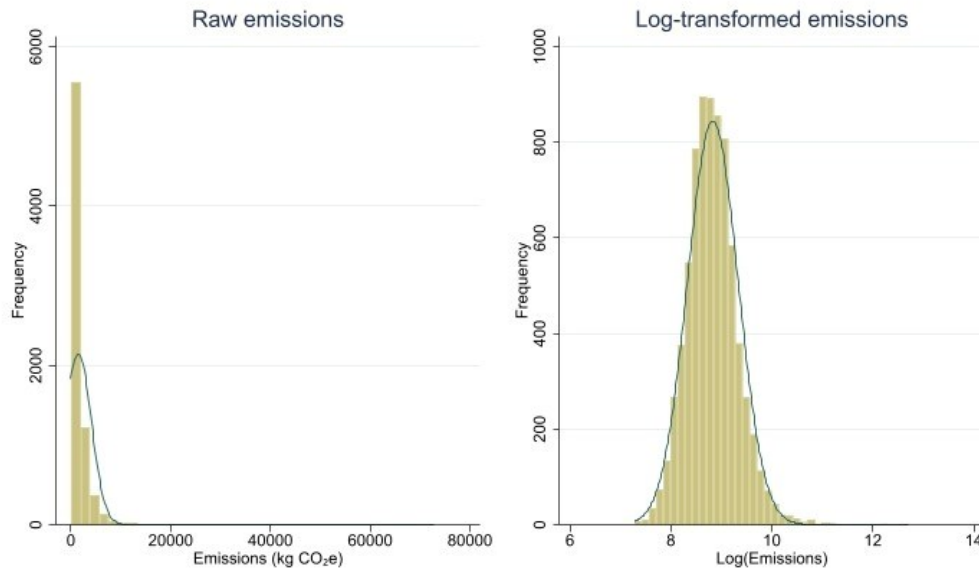
Variable	Role	Operationalisation	Interpretation
Annual VKT per capita	Dependent: H1, H3, H4	Annual household vehicle distance divided by household size; natural logarithm in regressions.	Mobility-service demand and direct rebound-like behaviour.
Total carbon footprint per capita	Dependent: H2	Consumption-based annual greenhouse-gas footprint; natural logarithm in regression.	Net household climate outcome including non-transport consumption.
EV ownership	Main explanatory	1 if household owns at least one battery electric vehicle; 0 for car-owning households without a BEV.	Technology/adoption status; mixed fleets may be included.
Income per capita	Control	Disposable income per capita; natural logarithm.	Confounder of EV adoption, mobility and footprint.
Household size	Control	Categorical; one-person household reference.	Captures per-capita economies of scale and mobility needs.
Degree of urbanisation	Control + H4 moderator	Cities (reference), towns/suburbs, rural areas.	Captures spatial structure and tests EV-by-place heterogeneity.
Country	Control	Iceland reference; Norway, Sweden, Finland, Denmark indicators.	Absorbs broad national institutional differences.
Climate concern (cc_worry)	H3 subgroup variable	Five-point item; 1-2 low, 4-5 high; midpoint 3 excluded from subgroup analysis.	Tests attitudinal heterogeneity; not a composite index.

Annual VKT per capita is the dependent variable for H1, H3, and H4. Its distribution in the analytical data is strongly right-skewed, so the regression uses the natural logarithm. The transformation reduces the influence of extreme high-mileage observations and permits proportional interpretation of coefficients. For a binary explanatory variable in a semilogarithmic model, the exact percentage difference is calculated as $100 \cdot [\exp(\beta) - 1]$ rather than $\beta \cdot 100$ when precision matters (Halvorsen and Palmquist, 1980).

Total consumption-based carbon footprint per capita is the dependent variable for H2. As shown in Figure 1, the original distribution is strongly right-skewed, while the natural-log transformation produces a substantially more symmetric distribution. The log-transformed outcome is therefore used in the regression analysis. The outcome includes supply-chain greenhouse-gas emissions associated with the wider household consumption basket rather than motor-fuel emissions alone (Heinonen et al., 2022; University of Iceland, 2024). This broader boundary is necessary for H2 because a transport-only outcome would not include emissions

associated with possible re-spending in other consumption categories (Hertwich, 2005; Font Vivanco et al., 2022).

Figure 1. Raw and log-transformed distributions of total consumption-based carbon footprint per capita



Income is included as the natural logarithm of disposable income per capita. It is a theoretically important confounder because income is associated with both EV adoption and the level and composition of household consumption (Rezvani et al., 2015; Nassen et al., 2015; Haustein et al., 2021). Higher-income households have greater purchasing capacity and generally larger consumption-based carbon footprints, while the budget importance of vehicle operating-cost savings can decline with income (Small and Van Dender, 2007; Heinonen et al., 2022). The logarithmic form also reduces skewness in the income variable.

Household size is included categorically with one-person households as the reference group. Because the dependent variables are per capita, these coefficients represent differences in per-person mobility or footprint across household sizes. Shared dwellings, vehicles, appliances, and some journeys create economies of scale in household consumption, making negative per-capita household-size coefficients substantively plausible even when total household consumption is greater (Nassen et al., 2015; Heinonen et al., 2022).

Degree of urbanisation follows the three-category classification used in the dataset: cities; towns and suburbs; and rural areas (University of Iceland, 2024). Cities form the reference group. Settlement type captures broad differences in density, accessibility, service proximity, and dependence on private mobility that are known to shape travel demand in Nordic contexts (Næss,

2012; Stjernborg and Lopez Svensson, 2024). It enters the baseline models as a control and is interacted with EV ownership for H4.

Country indicators account for broad cross-national differences between Denmark, Finland, Iceland, Norway, and Sweden, including EV policy maturity, charging systems, taxation, energy systems, and settlement structure (Holtmark and Skonhøft, 2014; Kester et al., 2018, 2020). Iceland is the reference country in the reported regressions. These indicators absorb country-level differences within the cross-section but do not identify the effects of particular national policies.

Climate concern is measured by the survey item *cc_worry* on a five-point Likert scale (University of Iceland, 2024). It is a single item rather than a composite index. For H3, responses 1 and 2 are classified as low concern, responses 4 and 5 as high concern, and midpoint response 3 is excluded from the subgroup comparison. Dichotomising a quantitative or ordinal scale sacrifices information and can reduce statistical efficiency, so this grouping is treated as a transparent exploratory contrast rather than an optimal measurement strategy (MacCallum et al., 2002). Climate concern is not a baseline H1 control; it is analysed explicitly as the H3 heterogeneity variable.

2.5 Empirical strategy

All reported models were estimated in Stata 18. The baseline analysis uses multivariable ordinary least squares regressions with log-transformed outcomes. The purpose is to estimate the conditional association between EV ownership and the outcome after accounting for observed socioeconomic, spatial, and country differences.

For H1, the model can be written as:

$$\ln(VKT_h) = \beta_0 + \beta_1 EV_h + \beta_2 \ln(Income_h) + \beta_3 HHS_h + \theta Urban_h + \gamma Country_h + \varepsilon_h$$

Here, VKT is annual vehicle-kilometres travelled per capita for household, EV indicates ownership of at least one battery electric vehicle, and the remaining terms represent the control variables described above. The coefficient of primary interest is β_1 . H1 predicts $\beta_1 > 0$. A positive and statistically significant coefficient would be consistent with a direct usage rebound mechanism; a coefficient that is zero or negative would provide no support for a positive direct driving rebound in this cross-sectional sample (Sorrell and Dimitropoulos, 2008; Gillingham et al., 2016).

For H2, the same set of baseline controls is applied to the log of total consumption-based carbon footprint per capita:

$$\ln(CF_h) = \alpha_0 + \alpha_1 EV_h + \alpha_2 \ln(Income_h) + \alpha_3 HHS_h + \theta Urban_h + \gamma Country_h + u_h$$

H2 predicts $\alpha_1 < 0$. Because CF is a total consumption-based outcome, the coefficient captures the conditional net footprint difference between EV-owning and non-EV car-owning households. It does not identify which consumption categories generate the difference and is not interpreted as a direct causal estimate of indirect rebound.

H3 examines climate-concern heterogeneity by estimating the H1-type VKT model separately in the low- and high-concern groups.

$$\ln(VKT_h) = \beta_{0g} + \beta_{1g} EV_h + \beta_{2g} \ln(Income_h) + \beta_{3g} HHS_h + \theta_g Urban_h + \gamma_g Country_h + \varepsilon_h$$

where $g \in \{\text{Low climate concern, High climate concern}\}$.

The comparison focuses on the EV coefficient in each subsample and therefore describes whether the conditional EV-VKT pattern is similar across the two attitudinal groups. A coefficient being significant in one subgroup and insignificant in another is not, however, evidence that the two coefficients are statistically different (Gelman and Stern, 2006). The split-sample result is consequently interpreted as exploratory heterogeneity rather than formal moderation; a pooled EV-by-concern interaction using the original scale would provide the stronger test.

H4 uses interaction terms between EV ownership and degree of urbanisation in the pooled VKT model:

$$\ln(VKT_h) = \beta_0 + \beta_1 EV_h + \sum_j \varphi_j (EV_h \times Urban_{hj}) + X_h' \delta + \varepsilon_h$$

The interaction coefficients indicate how the association between EV ownership and driving differs in towns/suburbs or rural areas relative to cities. The main settlement coefficients represent baseline differences between non-EV car-owning households across settlement types.

Statistical inference follows the coefficient estimates, standard errors, and p-values reported in the available regression output. Because both main outcomes are logged, the sign and magnitude are interpreted in proportional terms. For the EV dummy, the exact semilogarithmic

transformation $100 \times [\exp(\beta) - 1]$ is used (Halvorsen and Palmquist, 1980), yielding approximately -11.3% for $\beta = -0.1197$ in H1 and approximately -20.6% for $\beta = -0.2309$ in H2.

2.6 Research design, internal validity, and interpretation

The regression design improves on a raw EV versus non-EV comparison by adjusting for income, household size, urbanisation and country. These controls are substantively relevant because affluence and household composition are related to household carbon footprints, while settlement structure and national context are related to mobility and EV adoption (Nassen et al., 2015; Næss, 2012; Kester et al., 2018, 2020). The harmonised data also allow the same specification to be applied across five Nordic countries rather than one national sample.

Regression adjustment does not remove all selection bias in an observational cross-section. EV-adoption research shows that charging access, socioeconomic characteristics, travel needs and technology preferences can influence who adopts (Rezvani et al., 2015; Hardman et al., 2018; Haustein et al., 2021). Several related variables, including pre-adoption VKT, exact purchase date, fleet replacement versus addition, commuting distance and vehicle range, are not fully represented in the reported models. The coefficients are therefore interpreted as associations among households that are comparable on the observed controls, not as causal effects of EV adoption.

This limitation is particularly important for the term rebound. A formal direct rebound estimate requires a change in effective service price or efficiency and a counterfactual level of service demand (Sorrell and Dimitropoulos, 2008; Gillingham et al., 2016). Longitudinal or otherwise causally identified designs are better suited to estimating how VKT changes when technology and operating cost change (Ojeda-Diaz et al., 2025; Zhang et al., 2026). The present study asks the narrower question of whether the cross-sectional direction predicted by rebound theory is visible in the data.

The same caution applies to the carbon-footprint result. A lower conditional footprint among EV households could reflect lower transport emissions, different lifestyles, environmentally motivated consumption, a favourable budget trade-off, or unobserved selection. Rebound and household-footprint research makes all of these pathways plausible (Hertwich, 2005; Font Vivanco et al., 2022; Ottelin et al., 2024). H2 is therefore interpreted as a net consumption-based association rather than as an effect attributable entirely to EV technology.

Finally, the study separates descriptive evidence from regression evidence. Descriptive figures illustrate raw group differences in VKT or carbon footprint. Regression tables provide conditional associations after controls. Descriptive gaps are not described as adjusted effects, and adjusted coefficients are not converted into raw kilometre differences without a model-based prediction. This separation improves coherence between the graphical and statistical results and reduces the risk of overinterpreting simple group means.

2.6.1 Reproducibility and reporting

The reporting follows three consistency rules. VKT is defined throughout as annual vehicle-kilometres per capita and the carbon-footprint outcome as annual consumption-based greenhouse-gas emissions per capita. Regression tables use the same reference categories as the accompanying text and clearly distinguish main effects from interaction terms. Finally, interpretation follows the coefficient sign, uncertainty and model that is actually reported rather than the direction expected from theory.

Only analytical procedures supported by the available output are described. This is particularly relevant for the climate-concern analysis, where excluding midpoint responses changes the estimation sample, and for the settlement interaction model, where interpretation depends on the reference category and the interaction coefficients rather than on the rural main effect alone.

To keep the empirical workflow transparent, variable definitions and sample restrictions are stated in the Methods, while figures and tables are tied to the same outcome definitions used in the regression models. This makes it possible to trace each claim in the Results chapter back to a defined variable and specification and reduces the risk of mixing descriptive and adjusted results.

3. Results

The results are presented in the same order as the research questions and hypotheses. Section 3.1 evaluates the direct usage rebound hypothesis using annual VKT per capita. Section 3.2 evaluates the total consumption-based carbon-footprint outcome. Section 3.3 examines heterogeneity by climate concern. Section 3.4 tests EV-by-settlement interactions. The final subsection summarises the status of all four hypotheses.

3.1 EV ownership and annual vehicle-kilometres travelled per capita

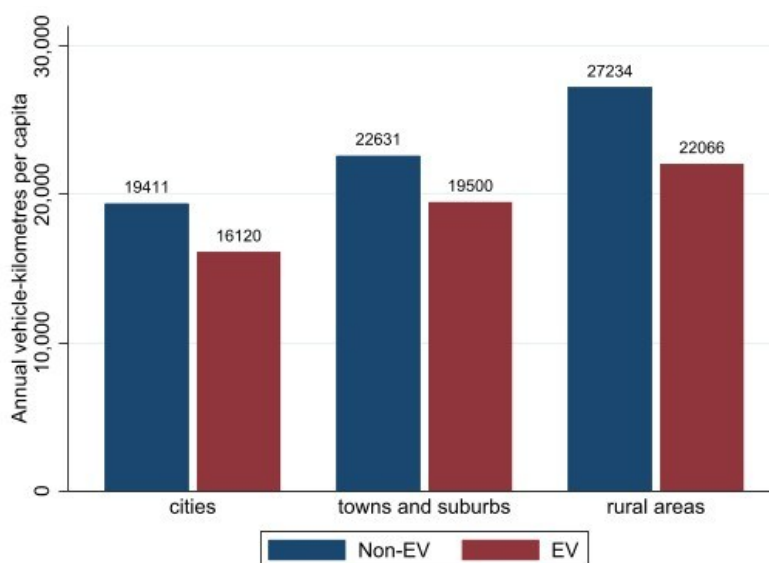
Table 3 reports the baseline regression for log annual VKT per capita. Surprisingly, the results show that EV ownership is negatively associated with vehicle-kilometres travelled, unlike some previous studies from Netherlands and Germany showing contradictory results (Zhang et al. 2025b; Huwe and Gessner 2020b). The coefficient on EV ownership is -0.1197 with a standard error of 0.0407 and $p = 0.003$. The sign is opposite to H1. Applying the exact dummy-variable transformation, $100 \times [\exp(-0.1197) - 1]$, EV-owning households have approximately 11.3% lower VKT per capita than non-EV car-owning households with the same values of the included income, household-size, settlement-type, and country controls. The result therefore provides no support for a positive direct usage rebound in the observed sample.

Table 3. Regression results for vehicle kilometers traveled

Dependent variable: ln(vkt)	R-squared=0.1760		
	Coeff.	Std.err	P> t
EV owners	-0.1197	0.0407	0.003
ln (Income)	0.3287	0.0224	0.000
Household size			
1 person (ref.)			
2 persons	-0.2180	0.0294	0.000
3 persons	-0.3441	0.0379	0.000
4 persons	-0.5523	0.0391	0.000
5 persons and more	-0.6372	0.0486	0.000
Degree of urbanization			
Cities (ref.)			
Towns and suburbs	0.2624	0.0272	0.000
Rural areas	0.4244	0.0281	0.000
Country			
Iceland (ref.)			
Norway	-0.0433	0.0355	0.223

Sweden	-0.2139	0.0331	0.000
Finland	0.1301	0.0330	0.000
Denmark	-0.0618	0.0517	0.231
Constant	5.6284	0.2421	0.000

Figure 2. Average VKT by EV ownership and degree of urbanisation



Income is positively associated with VKT in the reported model: the coefficient on log income is 0.3287 ($p < 0.001$). Household-size coefficients are negative relative to one-person households. Because the dependent variable is VKT per capita, these coefficients indicate lower per-person VKT in larger-household categories relative to the reference category; they should not be interpreted as evidence that total household travel is lower.

Settlement type is also strongly associated with VKT in this sample. Relative to cities, the coefficient is 0.2624 for towns and suburbs ($p < 0.001$) and 0.4244 for rural areas ($p < 0.001$). These are adjusted differences in per-capita VKT conditional on the variables in Table 3. Country coefficients show significantly lower VKT for Sweden and higher VKT for Finland relative to Iceland, while Norway and Denmark are not statistically different from Iceland at conventional levels.

The descriptive settlement-type pattern is shown in Figure 2. Raw mean VKT is higher in towns/suburbs and rural areas than in cities for both EV-owning and non-EV car-owning households. Within each settlement group, the descriptive mean for EV owners is lower than for

non-EV car owners. These raw means are illustrative and should not be treated as adjusted effects; Table 3 provides the conditional estimate.

Overall, H1 is not supported. The result does not mean that an EV causes a household to reduce driving by 11.3%. Rather, after adjustment for the observed covariates, EV ownership is associated with lower VKT in the cross-sectional sample, so the positive behavioural pattern expected under a direct usage rebound is not observed.

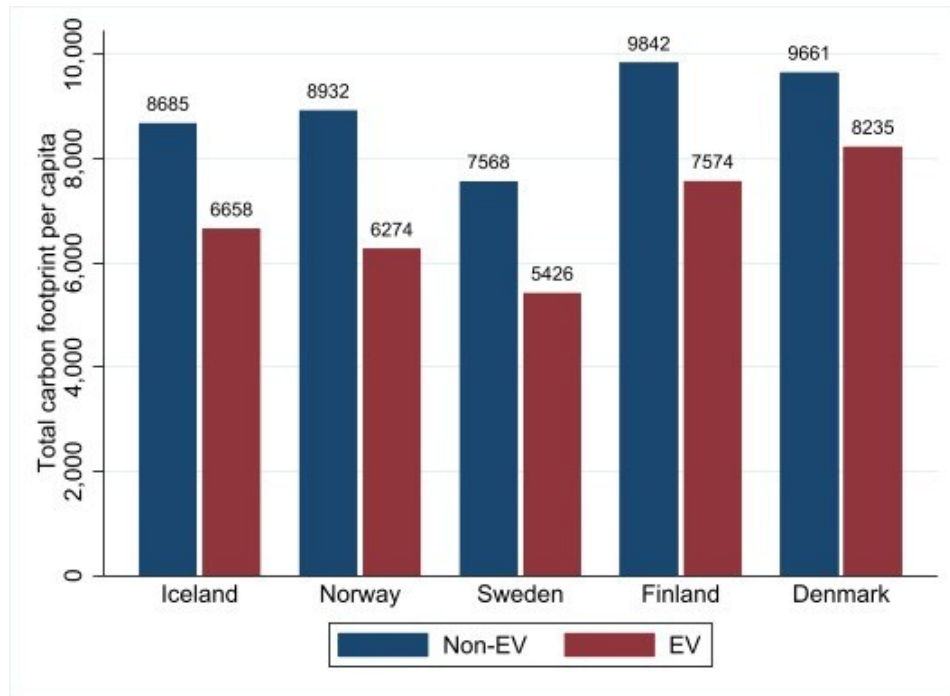
3.2 EV ownership and total consumption-based carbon footprint

Table 4 reports the regression for log total carbon footprint per capita. EV ownership has a coefficient of -0.2309 with a standard error of 0.0216 and $p < 0.001$. The exact transformation implies an approximately 20.6% lower total consumption-based carbon footprint per capita for EV-owning households than for non-EV car-owning households, conditional on the included socioeconomic, spatial, and country variables. H2 is therefore supported.

Table 4. Regression results for total carbon footprint emissions

Dependent variable: ln(CF)	R-squared=0.2040		
	Coeff.	Std.err	P> t
EV owners	-0.2309	0.0216	0.000
ln (Income)	0.2200	0.0119	0.000
Household size			
1 person (ref.)			
2 persons	-0.1525	0.0156	0.000
3 persons	-0.1860	0.0200	0.000
4 persons	-0.2680	0.0207	0.000
5 persons and more	-0.2175	0.0257	0.000
Degree of urbanization			
Cities (ref.)			
Towns and suburbs	0.0584	0.0144	0.000
Rural areas	0.0865	0.0149	0.000
Country			
Iceland (ref.)			
Norway	-0.0724	0.0188	0.000
Sweden	-0.1793	0.0175	0.000
Finland	0.1554	0.0175	0.000
Denmark	0.1250	0.0274	0.001
Constant	6.7984	0.1285	0.000

Figure 3. Total CF over EV ownership and country.



The income coefficient is 0.2200 ($p < 0.001$), so higher income is associated with a higher total consumption-based carbon footprint per capita in the adjusted model. Household-size coefficients are negative relative to one-person households, describing lower per-capita footprints in the larger household categories. Town/suburban and rural households have higher adjusted footprints than city households, although these spatial coefficients are smaller than those in the VKT model.

Country coefficients show meaningful cross-national variation after adjustment. Relative to Iceland, Norway and Sweden have lower carbon footprints, while Finland and Denmark have higher footprints in this model. These differences should be interpreted as country fixed effects that absorb a broad set of national differences rather than as the isolated effect of electricity mix or any single policy.

Figure 3 presents unadjusted mean total carbon footprints by EV ownership and country. EV-owning households have lower descriptive mean footprints in each of the five countries shown. The consistency of the raw pattern is notable, but the regression result remains the preferred basis for inference because it accounts for differences in income, household size, settlement type, and country.

The H2 result should be interpreted as a net household-footprint association. Because the outcome covers the wider consumption basket, it is compatible with the possibility that indirect rebound is already embedded in the observed footprint. However, the model does not identify whether fuel savings were re-spent, whether vehicle purchase cost constrained other consumption, or whether environmentally oriented lifestyles explain part of the group difference. Those mechanisms are evaluated in the Discussion rather than inferred directly from the coefficient.

3.3 Heterogeneity by climate concern

H3 examines whether the association between EV ownership and annual VKT per capita differs between households with low and high climate concern. Table 5 presents separate regression models for the two climate-concern groups to show how the associations between VKT and the explanatory variables vary across the subsamples. In addition, a pooled interaction model was estimated to formally test whether the EV coefficient differs between the two groups

Figure 4. Descriptive annual VKT per capita by EV ownership and climate-concern group

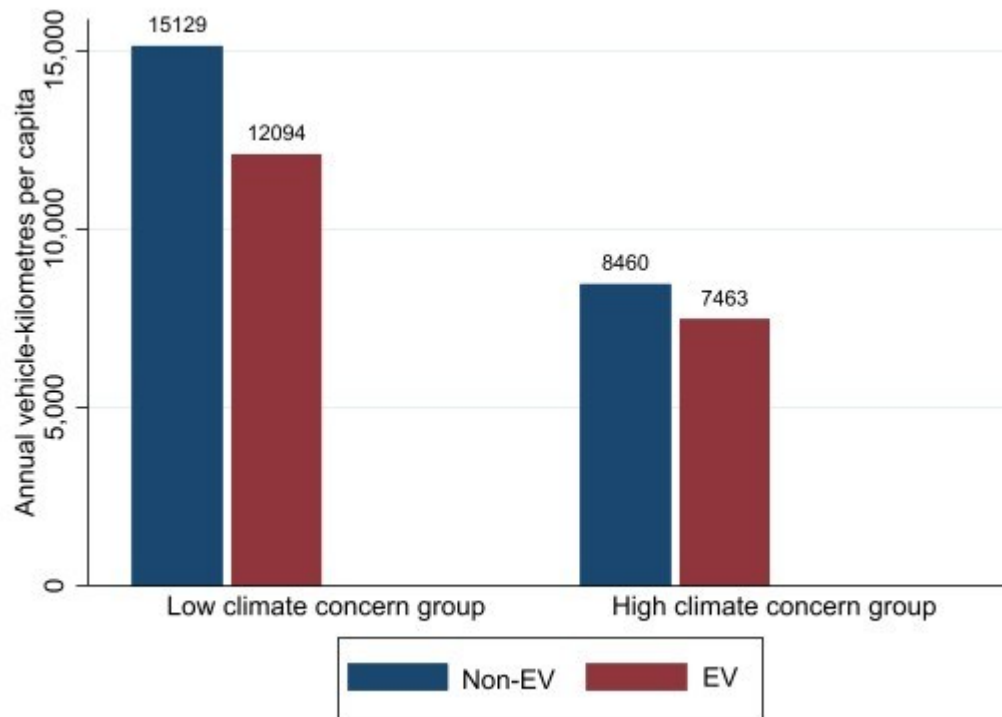


Table 5. EV coefficient in VKT regressions by climate-concern group

Dependent variable: ln(vkt)	R-squared=0.1680			R-squared=0.1880		
	High climate concern			Low climate concern		
	Coeff.	Std.err	P> t	Coeff.	Std.err	P> t
EV owners	0.0048	0.0489	0.921	-0.3397	0.1362	0.013
ln (Income)	0.3193	0.0302	0.000	0.3889	0.0459	0.000
Household size						
1 person (ref.)						
2 persons	-0.1730	0.0396	0.000	-0.2529	0.0609	0.000
3 persons	-0.3460	0.0508	0.000	-0.2760	0.0789	0.000
4 persons	-0.5599	0.0523	0.000	-0.4023	0.0850	0.000
5 persons and more	-0.6348	0.0671	0.000	-0.5672	0.0957	0.000
Degree of urbanization						
Cities (ref.)						
Towns and suburbs	0.2934	0.0353	0.000	0.1456	0.0607	0.017
Rural areas	0.4337	0.0388	0.000	0.2742	0.0577	0.000
Country						
Iceland (ref.)						
Norway	-0.0865	0.0515	0.093	0.0277	0.0704	0.694
Sweden	-0.2781	0.0435	0.000	0.0425	0.0761	0.576
Finland	0.0401	0.0449	0.372	0.3065	0.0695	0.000
Denmark	-0.0736	0.0449	0.372	-0.0375	0.1434	0.794
Constant	5.6511	0.3246	0.000	5.1859	0.5007	0.000

The clearest difference concerns EV ownership. Among respondents with low climate concern, EV ownership is negatively and statistically significantly associated with VKT per capita ($\beta=-0.3397$, SE = 0.1362, $p=0.013$). Using the exact transformation for a dummy variable in a semilogarithmic model, this corresponds to approximately 28.8% lower annual VKT per capita among EV-owning households compared with non-EV car-owning households with otherwise similar observed characteristics.

Among respondents with high climate concern, the EV coefficient is close to zero ($\beta=0.0048$, SE = 0.0489, $p=0.921$). This corresponds to an estimated VKT difference of less than 1%, providing no evidence of a meaningful EV/non-EV difference within the high-concern subgroup.

The difference between these two coefficients was tested formally in a pooled model containing an interaction between EV ownership and climate-concern group. The interaction was positive and statistically significant ($\beta=0.3478$, SE = 0.1492, $p=0.020$). A formal test of the interaction

gave $F(1,4467)=5.44$, $p=0.0198$. The null hypothesis that the EV–VKT association is identical in the two climate-concern groups is therefore rejected. H3 is supported.

The remaining coefficients in Table 5 also show some differences between the two groups. Income is positively associated with VKT in both subsamples, although the coefficient is somewhat larger among respondents with low climate concern ($\beta=0.3889$) than among those with high concern ($\beta=0.3193$). Household-size coefficients are negative in both groups, consistent with the per-capita definition of VKT. Settlement type is also positively associated with VKT in both subsamples. Relative to cities, town/suburban and rural households have higher VKT, although these spatial differences are larger in the high-concern model.

Country patterns differ more noticeably between the two groups. Sweden is associated with substantially lower VKT relative to Iceland among high-concern respondents, whereas the corresponding coefficient is small and statistically insignificant among low-concern respondents. Finland shows the opposite pattern, with a strong positive coefficient in the low-concern group but only a small and insignificant coefficient in the high-concern group. These subgroup differences are descriptive and are not interpreted as formally significant differences unless an interaction is tested specifically for the relevant variable.

Overall, the H3 results indicate that climate concern is associated with meaningful heterogeneity in the EV-VKT relationship. The negative EV association is concentrated among respondents with low climate concern, while EV and non-EV households with high climate concern have almost identical adjusted VKT.

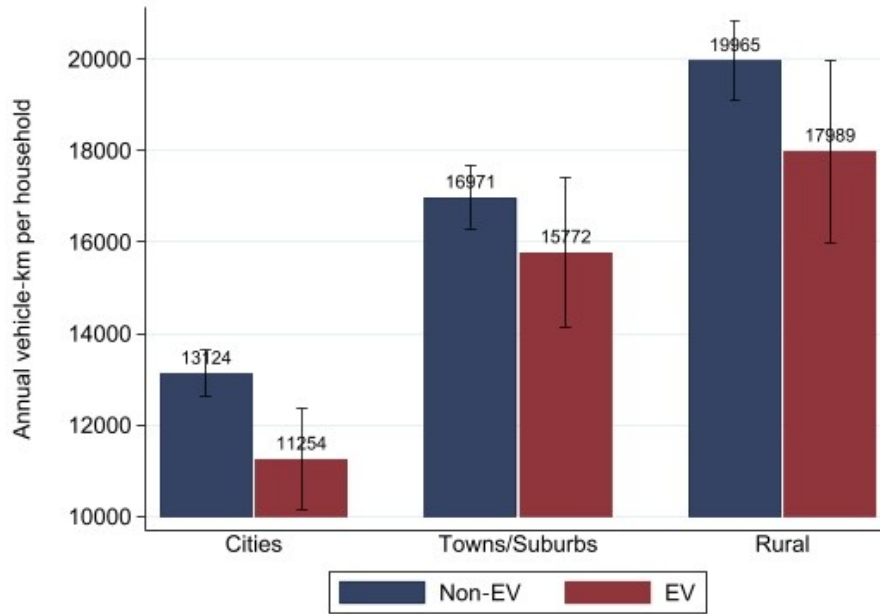
3.4 Spatial heterogeneity in the EV-VKT association

H4 examined whether the association between EV ownership and annual VKT per capita differs across cities, towns and suburbs, and rural areas. To test this hypothesis, EV ownership was interacted with degree of urbanisation in the pooled VKT regression, with cities used as the reference category.

Table 6. Regression results for degree of urbanization

Dependent variable: ln(vkt)	R-squared=0.1762		
	Coeff.	Std.err	P> t
EV owners	-0.1593	0.5756	0.006
ln (Income)	0.3287	0.0224	0.000
Household size			
1 person (ref.)			
2 persons	-0.2186	0.0294	0.000
3 persons	-0.3437	0.0379	0.000
4 persons	-0.5531	0.0391	0.000
5 persons and more	-0.6375	0.0486	0.000
Degree of urbanization			
Cities (ref.)			
Towns and suburbs	0.2546	0.0284	0.000
Rural areas	0.4188	0.0290	0.000
Interaction terms			
Cities × EV (ref.)			
Towns and suburbs × EV	0.0849	0.0916	0.353
Rural areas × EV	0.0668	0.1064	0.529
Country			
Iceland (ref.)			
Norway	-0.0425	0.0356	0.232
Sweden	-0.2131	0.0331	0.000
Finland	0.1314	0.0331	0.000
Denmark	-0.0617	0.0517	0.232
Constant	5.6319	0.2426	0.000

Figure 5. Descriptive annual VKT by EV ownership and settlement type.



The EV coefficient for city households was negative and statistically significant ($SE = 0.0576$). In a semilogarithmic model, this corresponds to approximately 14.7% lower annual VKT per capita among EV-owning city households than among otherwise comparable non-EV car-owning city households.

The $EV \times \text{town/suburb}$ interaction was positive but statistically insignificant ($SE = 0.0915$), while the $EV \times \text{rural}$ interaction was also statistically insignificant ($SE = 0.1062$). A joint test of the two interaction terms likewise failed to reject the null hypothesis that the EV–VKT association is identical across settlement categories.

Average marginal effects provide a more intuitive interpretation of the interaction model. EV ownership was associated with approximately 14.7% lower VKT per capita in cities, 7.2% lower VKT in towns and suburbs, and 8.8% lower VKT in rural areas. Although the point estimates differ numerically, the interaction test shows that these differences are not statistically distinguishable.

Settlement type itself remained strongly associated with baseline VKT. Relative to city households, town/suburban households had a coefficient of 0.2547 and rural households a coefficient of 0.4188 . These main effects indicate higher baseline VKT outside cities but should not be interpreted as evidence of stronger EV rebound. Overall, H4 is not supported: the analysis

provides no statistically significant evidence that degree of urbanisation moderates the association between EV ownership and VKT.

3.5 Summary of hypotheses

Table 7 summarises the empirical findings in a form that links each hypothesis to the relevant model and prevents results from being described under the wrong research question.

Table 7. Summary of hypotheses and empirical conclusions

Hypothesis	Prediction	Key result	Conclusion
H1	EV owners have higher VKT per capita	EV coefficient = -0.1197, $p = 0.003$ (~11.3% lower VKT)	Not supported
H2	EV owners have lower total carbon footprint per capita	EV coefficient = -0.2309, $p < 0.001$ (~20.6% lower CF)	Supported
H3	EV-VKT association differs by climate concern	EV $\times$ high-concern interaction: $\beta = 0.3478$, $p = 0.020$; joint test: $F(1,4467) = 5.44$, $p = 0.0198$	Supported
H4	EV-VKT association differs by settlement type	EV $\times$ town $p=0.353$; EV $\times$ rural $p=0.529$	Not supported

The main result is that the data do not show a positive EV-VKT association. Instead, the baseline EV coefficient is negative. The broader carbon-footprint result is also negative and statistically significant. Climate concern is associated with a markedly different overall level of driving and with heterogeneous subgroup EV coefficients, but the subgroup design does not establish formal moderation. Settlement type strongly predicts baseline VKT, yet the EV interaction with settlement is not statistically significant. These four findings provide the structure for the Discussion chapter.

4. Discussion

This thesis examined whether EV ownership among car-owning households in the Nordic countries is associated with patterns consistent with a direct driving rebound, and whether these patterns vary with climate concern and settlement type. It also considered whether differences in mobility are reflected in the wider consumption-based carbon footprint of households.

Four main findings emerge. First, EV ownership is associated with lower rather than higher annual VKT per capita after adjustment for income, household size, settlement type and country. Second, EV-owning households also have a lower total consumption-based carbon footprint per capita. Third, the EV–VKT association differs significantly between low- and high-climate-concern households: the negative EV association is concentrated among respondents with low climate concern, while virtually no EV/non-EV difference is observed among respondents with high concern. Finally, although households outside cities have substantially higher VKT, there is no statistically significant evidence that the EV–VKT association itself differs across cities, towns and suburbs, and rural areas.

Taken together, these results do not support a simple interpretation in which lower EV operating costs automatically lead to additional driving. They instead point to a combination of household selection, mobility constraints, attitudes, spatial structure and vehicle-use conditions that shape how electric vehicles are used.

4.1 RQ1 and H1: no evidence of a positive direct driving rebound

H1 predicted that lower EV operating costs would be associated with higher VKT per capita. The estimated EV coefficient is instead -0.1197, corresponding to approximately 11.3% lower VKT after adjustment for income, household size, settlement type, and country. The central interpretation is therefore negative evidence for the predicted direction: a positive direct usage rebound is not visible in the observed Nordic sample.

The H1 result differs from the conventional road-transport literature, where lower effective driving cost is usually associated with some increase in travel. Small and Van Dender (2007) and the meta-analysis by Dimitropoulos et al. (2018) both support that general mechanism. The contrast does not mean that rebound theory is wrong; an EV ownership coefficient reflects more than operating cost because it also captures adopter characteristics, range, charging access, purchase cost, fleet composition and market stage.

The result is closer to the part of the EV literature that finds weak, absent or negative mileage differences. Zhao et al. (2023) report lower BEV mileage on average in the United States, with the gap narrowing as electric range improves. Zhang et al. (2025) find no positive BEV effect on VKT or trip frequency in the Netherlands. These findings suggest that lower operating cost does not necessarily translate into higher observed mileage when vehicle capability, selection and travel context are taken into account.

Other studies show that a positive behavioural response is possible. Green and Ostli (2025) find increased car-trip demand and substitution from other modes in Norway, while charging research shows that EV use changes with charging access and routines (Tal et al., 2014; Hardman et al., 2018). The coexistence of positive, null and negative estimates is consistent with recent reviews, which describe EV rebound as dependent on the outcome, counterfactual, market stage and analytical scale (Ojeda-Diaz et al., 2025; Zhang et al., 2026).

Selection into EV ownership is one plausible explanation for the negative H1 coefficient. Reviews and adoption studies show that EV owners are not randomly drawn from the population of drivers; adoption is related to socioeconomic characteristics, environmental attitudes, technology perceptions, range expectations and charging access (Rezvani et al., 2015; Westin et al., 2018; Haustein et al., 2021). If households whose travel patterns were already well suited to EV technology adopted earlier, part of the lower observed VKT could pre-date the vehicle choice. The -11.3% estimate is therefore interpreted as an adjusted association rather than a causal reduction caused by the EV.

Range offers a concrete example of this selection process. Zhao et al. (2023) find that BEV mileage rises relative to gasoline-vehicle mileage as electric driving range improves. This suggests that vehicle capability affects realised use and may also affect which households choose to adopt. Range and charging constraints are well-established adoption and usability factors more broadly (Rezvani et al., 2015; Hardman et al., 2018; Haustein et al., 2021). The 2021-2022 survey therefore captures a market that was already advanced but still evolving in both vehicle capability and adopter composition.

Household fleet composition can also weaken the link between EV operating cost and total household VKT. Multi-vehicle households can allocate short or routine trips to an EV while retaining another vehicle for travel that is less compatible with range or charging constraints, so kilometres can be redistributed within the fleet without increasing household mobility (Tamor

and Milacic, 2015; Bjornsson and Karlsson, 2017; Jensen and Mabit, 2017). Because the present EV indicator includes mixed fleets, the H1 coefficient averages across replacement and addition pathways that may have different rebound responses.

There may also be limited room to expand mobility demand. Travel is constrained by time, work and school schedules, service locations and household responsibilities as well as by money. This is consistent with the conventional finding that long-run rebound is larger than short-run rebound because households need time to alter locations, fleets and routines (Dimitropoulos et al., 2018). In high-income households, the saving from lower vehicle energy cost can also form a relatively small share of the budget, which can reduce price sensitivity (Small and Van Dender, 2007).

Institutional context provides another reason not to expect operating cost to act alone. Nordic EV systems have developed through combinations of taxation, tolls, purchase incentives and charging provision, while congestion, parking, travel time and spatial accessibility remain important parts of the cost of mobility (Bjerkkan et al., 2016; Kester et al., 2018). Electrification changes the energy carrier, but it does not remove these non-energy constraints. The H1 result is therefore compatible with a setting in which cheaper energy per kilometre is only one component of the decision to travel.

The most defensible conclusion from H1 is therefore limited. Among car-owning households with similar observed income, household size, settlement type and country, EV ownership is not associated with higher VKT per capita in this dataset. This fits a growing literature in which a positive rebound is possible but not universal (Ojeda-Diaz et al., 2025; Zhang et al., 2026).

4.2 RQ2 and H2: lower total carbon footprint and the role of indirect or desirable rebound

H2 is supported: EV ownership is associated with an approximately 20.6% lower total consumption-based carbon footprint per capita. The important point is that the dependent variable extends beyond vehicle operation. A transport-only measure could show lower fuel emissions while missing compensating emissions elsewhere in the household budget (Hertwich, 2005; Font Vivanco et al., 2022). In the present data, the conditional difference remains negative even when the wider consumption basket is included.

A lower total footprint is plausible in the Nordic context because the life-cycle greenhouse-gas advantage of EVs improves as the electricity used for operation becomes less carbon-intensive

(Hawkins et al., 2013). Nordic electricity systems contain substantial low-carbon generation, although national mixes differ (Heinonen et al., 2022). This thesis does not perform a new vehicle life-cycle assessment, so the electricity context is used only as background for interpreting H2, not as a decomposition of the coefficient.

The household-budget perspective is just as important. Ottelin et al. (2024) show that mobility-related footprint differences in Nordic households are altered by income, household structure and consumption in other domains. Lower transport emissions therefore do not translate automatically into an equally large reduction in total footprint. The standard indirect-rebound mechanism is one possible reason, since efficiency savings can be re-spent on other carbon-intensive activities (Hertwich, 2005; Font Vivanco et al., 2022).

Because H2 uses total consumption-based carbon footprint, the model already includes emissions from non-transport consumption. In that sense, the net outcome of any re-spending that occurred during the measurement period is present in the dependent variable (Heinonen et al., 2022; University of Iceland, 2024). What the model cannot identify is the causal pathway. It cannot isolate a monetary fuel saving, follow that money to a later purchase, and calculate the share of technical EV savings that was offset. That would require longitudinal household budgets or a structural expenditure model (Font Vivanco et al., 2022; Ottelin et al., 2024).

A budget response can also reinforce the saving rather than reduce it. Font Vivanco et al. (2022) note that rebound-related changes in consumption can have environmentally beneficial directions when one type of expenditure displaces another. For EVs, lower running costs may coexist with a comparatively high upfront purchase cost, which could temporarily constrain other consumption. Nordic evidence on cross-domain trade-offs makes this possibility relevant, but it does not show that vehicle purchase cost caused the lower footprint observed in this sample (Ottelin et al., 2024).

The data therefore do not establish that a desirable rebound occurred. The lower H2 coefficient is compatible with several explanations, including lower transport emissions, environmentally oriented lifestyles among EV adopters, differences in housing or consumption preferences, and selection of households that already had lower footprints before purchase (Rezvani et al., 2015; Árnadóttir et al., 2024; Ottelin et al., 2024). Distinguishing these mechanisms would require category-level carbon-footprint data together with information on vehicle purchase timing and expenditure.

The positive income coefficient also places H2 within a wider pattern found in household-footprint research. Higher income and higher consumption are consistently associated with larger greenhouse-gas footprints across housing, mobility, goods, services and leisure (Nassen et al., 2015; Barros and Wilk, 2021; Heinonen et al., 2022). EV ownership can therefore be associated with a lower footprint at a given observed income without implying that electrification alone addresses the emissions associated with affluent consumption.

The negative household-size coefficients are also consistent with the per-capita definition of the outcome. Household consumption contains shared components, so per-person footprints often fall as household size increases even when total household emissions rise (Nassen et al., 2015; Heinonen et al., 2022). The same unit distinction applies to VKT, which is why 'per capita' is used consistently in the methods, tables, figures and interpretation.

Overall, H2 strengthens the environmental relevance of H1. The absence of a positive EV-VKT association is not accompanied by evidence that broader consumption fully offsets the carbon-footprint advantage. Yet the cross-sectional design prevents a simple causal claim that EV adoption itself lowers total household carbon footprint by 20.6%. The defensible conclusion is that EV-owning households have a lower adjusted total consumption-based footprint in the observed sample, and that this difference survives the inclusion of the wider household consumption basket.

4.3 RQ3 and H3: climate concern changes the pattern, but not in the originally expected direction

The H3 analysis provides statistically significant evidence that the association between EV ownership and VKT differs between low- and high-climate-concern households. This is an important improvement over a simple comparison of separate regression significance levels because the pooled $EV \times \text{climate-concern}$ interaction directly tests whether the two EV coefficients differ. The interaction is statistically significant ($p=0.020$), and the formal test gives $F(1,4467)=5.44$, $p=0.0198$. H3 is therefore supported.

The direction of the heterogeneity is particularly noteworthy. Among respondents with low climate concern, EV ownership is associated with approximately 29% lower annual VKT per capita than non-EV car ownership after adjustment for income, household size, settlement type and country. Among respondents with high climate concern, by contrast, the EV/non-EV difference is effectively zero. The result therefore does not suggest that stronger climate concern

strengthens a negative EV–VKT association. Instead, the pronounced difference between EV and non-EV households appears in the low-concern group.

This pattern needs to be distinguished from the broader relationship between environmental concern and mobility. Environmental-behaviour research has repeatedly shown that environmental attitudes can be associated with lower-impact behaviour, although these relationships vary considerably across behaviours and contexts (Stern, 2000; Bamberg and Moser, 2007; Steg and Vlek, 2009). Nordic evidence likewise shows an association between stronger climate concern and lower consumption-based carbon footprints (Árnadóttir et al., 2024). Climate concern may therefore be related to general mobility preferences or lifestyles without necessarily creating an additional difference between EV and non-EV households within the high-concern group.

One possible explanation for the strong negative EV coefficient among low-concern respondents is selection into EV ownership. Adoption of an EV depends not only on environmental motivation but also on vehicle range, charging access, costs, travel requirements and perceptions of the technology (Rezvani et al., 2015; Haustein et al., 2021). Among households with relatively little climate motivation, the decision to adopt an EV may therefore have been more dependent on whether their existing mobility pattern was already well suited to electric driving. For example, low-concern households with moderate annual mileage, reliable charging access or fewer long-distance requirements may have been more willing to adopt an EV than otherwise similar high-mileage households. Evidence that realised BEV mileage changes with vehicle range makes this type of selection mechanism plausible (Zhao et al., 2023).

This interpretation, however, remains a possible mechanism rather than a finding of the present analysis. The data do not contain pre-adoption VKT or sufficiently detailed information on the travel requirements, charging conditions and vehicle characteristics faced by households when they acquired an EV. It is therefore impossible to determine whether the negative EV coefficient among low-concern respondents reflects behavioural change after adoption or pre-existing differences between households that selected different vehicle technologies.

The subgroup regressions also suggest that the relationship between mobility and structural characteristics is not identical across the two concern groups. Income is positively related to VKT in both groups, while household size is negatively associated with per-capita VKT. Town/suburban and rural residence are also positively associated with VKT in both models. At

the same time, the magnitude of some country and settlement coefficients differs across the two subsamples. These patterns reinforce the idea that climate concern does not operate independently of socioeconomic and spatial circumstances. However, because H3 formally tests only the EV $\times$ climate-concern interaction, differences in the other coefficients should not be interpreted as statistically established group differences without additional interaction tests.

The finding also illustrates why climate concern should not be treated as a simple proxy for environmentally beneficial behaviour. A household can be strongly concerned about climate change while still facing long commuting distances, limited public-transport alternatives or other practical requirements that constrain its ability to reduce driving. Conversely, a household with relatively low stated climate concern may have low VKT because of residential location, work arrangements or other factors unrelated to environmental motivation. The observed interaction is therefore likely to reflect a combination of attitudes, technology selection and structural mobility conditions.

The most appropriate conclusion is consequently narrower than saying that climate concern causes a different response to EV ownership. The cross-sectional design cannot establish such a causal pathway. Instead, the analysis shows that the conditional association between EV ownership and VKT differs significantly by climate-concern group. EV ownership is associated with substantially lower VKT among low-concern respondents, whereas there is essentially no EV/non-EV difference among high-concern respondents. This supports H3 while also demonstrating that the relationship between environmental attitudes, technology adoption and mobility is more complex than a simple assumption that greater climate concern necessarily produces a stronger reduction in travel.

4.4 RQ4 and H4: strong spatial differences in mobility, but no significant EV-by-settlement interaction

The results show a clear distinction between differences in baseline mobility across settlement types and differences in the association between EV ownership and VKT. Town/suburban and rural households have significantly higher annual VKT per capita than city households. In the interaction model, the coefficients for towns and suburbs ($\beta=0.2547$, $p<0.001$) and rural areas ($\beta=0.4188$, $p<0.001$) are both positive relative to cities. This pattern is consistent with previous Nordic research showing that lower-density settlements are generally associated with longer

travel distances and stronger dependence on private cars because employment, services and other destinations are more dispersed (Næss, 2012; Stjernborg and Lopez Svensson, 2024).

These settlement differences, however, should not be interpreted as evidence of a stronger rebound effect outside cities. H4 concerns whether the association between EV ownership and VKT changes across settlement types, rather than whether rural and urban households have different overall levels of travel. The EV $\times$ town/suburb interaction is positive but statistically insignificant ($\beta=0.0849$, $p=0.353$), and the EV $\times$ rural interaction is also insignificant ($\beta=0.0669$, $p=0.529$). A joint test of both interaction terms leads to the same conclusion, $F(2,5790)=0.49$, $p=0.614$. The analysis therefore provides no statistically significant evidence that the EV–VKT association differs systematically between cities, towns and suburbs, and rural areas.

The marginal effects help illustrate this result. EV ownership is associated with approximately 14.7% lower VKT per capita among city households, and this estimate is statistically significant ($p=0.006$). The estimated differences are also negative in towns and suburbs, at approximately 7.2%, and in rural areas, at approximately 8.8%, although neither estimate is statistically significant ($p=0.302$ and $p=0.303$, respectively). Importantly, the significance of the city estimate and the non-significance of the other two estimates do not demonstrate that the effects are different from one another. The interaction terms and the joint test provide the appropriate statistical comparison, and both indicate that the differences between settlement categories are not statistically distinguishable.

One possible explanation is that high rural VKT reflects structural mobility needs rather than a greater behavioural response to lower operating costs. Rural households often travel longer distances to employment, education, healthcare, shopping and other services, while alternatives to private cars can be limited (Næss, 2012; Stjernborg and Lopez Svensson, 2024). If a substantial share of these journeys is necessary, lower EV operating costs may reduce the financial cost of existing mobility without necessarily generating a large amount of additional travel. This provides a plausible explanation for why rural households can have considerably higher baseline VKT while showing no statistically stronger EV-related association.

EV-specific constraints may also help explain why lower operating costs do not translate automatically into additional rural travel. Long-distance journeys place greater importance on vehicle range and charging availability, while low temperatures can reduce effective battery range and affect fast-charging performance (Delos Reyes et al., 2016; Motoaki et al., 2018).

Access to reliable charging infrastructure is also an important determinant of EV usability (Hardman et al., 2018; Kester et al., 2020). These factors may limit the extent to which lower electricity costs alone influence additional travel, particularly for households undertaking long or less flexible journeys.

The results should nevertheless not be interpreted as proof that settlement type has no moderating role. The confidence intervals around the settlement-specific EV effects remain relatively wide, particularly outside cities, meaning that modest differences cannot be ruled out. The appropriate conclusion is therefore narrower: the present sample does not provide sufficient statistical evidence that the association between EV ownership and VKT varies by degree of urbanisation. H4 is consequently not supported.

From a policy perspective, the findings suggest that electrification and accessibility address different dimensions of mobility. EVs can contribute to reducing the carbon intensity of car travel, particularly where private-car use is difficult to substitute, but electrification itself does not alter the underlying distances between households and workplaces, schools, healthcare or other services. Charging availability and vehicle reliability therefore remain important for electrification, while accessibility planning and viable alternatives to private-car travel remain relevant for reducing structurally high mobility demand (Kester et al., 2020; Stjernborg and Lopez Svensson, 2024).

4.5 Contribution to the rebound literature

Taken together, the four results clarify several points that are sometimes blurred in EV rebound debates. The first thesis distinguishes between a theoretical rebound mechanism and an observed difference between EV-owning and non-EV households. The study does not estimate a conventional rebound elasticity because it does not observe an exogenous change in operating cost or the same households before and after EV adoption. Instead, it tests whether the positive VKT pattern predicted by direct-rebound theory can be detected in a cross-sectional comparison. In this sample, it cannot.

This result contributes to an increasingly mixed EV literature. Positive behavioural responses have been identified in some settings, including increased car demand in Norway, while other studies report no positive effect or lower BEV mileage (Green and Ostli, 2025; Zhao et al., 2023; Zhang et al., 2025). The present findings reinforce the view that there is unlikely to be one universal EV rebound rate. The observed response depends on the outcome being measured, the

comparison group, household fleet structure, vehicle capability, adopter selection and the maturity of the EV market (Ojeda-Diaz et al., 2025; Zhang et al., 2026).

Second, the thesis connects mobility demand with the wider household carbon footprint. Rebound from lower mobility expenditure does not have to appear as additional kilometres. It can emerge elsewhere in household consumption. By analysing total consumption-based carbon footprint alongside VKT, the study incorporates the net emissions associated with the wider consumption basket, while recognising that the cross-sectional data cannot reconstruct the underlying expenditure pathway.

Third, the climate-concern analysis provides evidence that environmental attitudes are associated with heterogeneity in the EV–VKT relationship. The formal interaction shows that the EV coefficient differs significantly between low- and high-concern respondents. Importantly, the stronger negative EV association occurs among the low-concern group rather than among respondents with greater climate concern. This finding challenges a simple assumption that stronger environmental concern necessarily intensifies the mobility effect associated with EV ownership.

Fourth, the spatial analysis separates high car dependence from spatially stronger rebound. Rural and town/suburban households have substantially higher VKT than city households, but the formal interaction analysis does not show that the EV/non-EV contrast differs significantly across settlement types. This distinction prevents high rural mileage from being interpreted incorrectly as evidence of a stronger rural rebound.

More generally, the study shows the value of maintaining consistent outcome definitions and comparison groups. VKT is measured per capita throughout the final models, the comparison group consists of non-EV car-owning households, total carbon footprint is distinguished from transport emissions, and heterogeneity hypotheses are evaluated using formal interaction tests. These distinctions are important because apparently similar rebound questions can refer to materially different estimands.

4.6 Policy implications

The findings support EV electrification as one component of transport decarbonisation, but they also show why electrification should not be treated as a complete mobility strategy. In the present sample, there is no evidence that EV ownership is associated with additional VKT that would

offset environmental benefits through a direct driving-rebound channel. EV-owning households are instead associated with both lower VKT and a lower total consumption-based carbon footprint.

Technology alone, however, does not determine household mobility. Settlement type remains strongly associated with travel demand, while income is positively associated with both VKT and total carbon footprint. Accessibility, household resources and broader consumption therefore remain relevant even after the drivetrain changes.

The climate-concern result also cautions against relying primarily on environmental awareness as a policy instrument. Climate concern is clearly related to the pattern of mobility, but the significant interaction does not show that stronger concern creates a larger EV-related reduction in VKT. Environmental attitudes operate alongside travel requirements, infrastructure and technology selection. Policies that make lower-carbon behaviour practical may therefore be more effective than assuming that awareness alone will translate into reduced mobility.

The rural results make this distinction particularly clear. Where long distances and limited alternatives make car use difficult to avoid, electrification can reduce the emissions intensity of necessary mobility. Reducing the amount of travel requires a different set of interventions related to accessibility, public transport, service location and other alternatives to private cars.

Finally, the H2 result supports evaluating transport policy beyond tailpipe emissions. Consumption-based accounting highlights the possibility that savings in one domain can be offset or reinforced by consumption elsewhere. Household-level climate policy should therefore consider both technological substitution and broader patterns of consumption.

4.7 Methodological limitations

Several limitations remain important when interpreting the results.

First, the study is cross-sectional. Different households are compared at one point in time rather than following the same households before and after EV adoption. This prevents causal estimation of the effect of switching to an EV. The EV coefficient can reflect pre-existing differences in mobility, environmental preferences, charging access, vehicle characteristics or other unobserved factors.

Second, EV ownership is measured at household level and does not distinguish clearly between an all-electric fleet, a mixed EV–ICE fleet, replacement of an existing car and addition of another

vehicle. These configurations may generate different travel responses. More detailed information on household fleets would allow the behavioural mechanism to be identified more precisely.

Third, the analysis does not estimate a conventional rebound elasticity. A formal rebound estimate would require a measured change in effective cost per kilometre and a counterfactual level of service demand. Here, EV ownership is used as the exposure. The findings should therefore be described as evidence about patterns consistent or inconsistent with a direct usage rebound rather than as a percentage of technical energy savings taken back through additional travel.

Fourth, climate concern is measured using a single survey item and is grouped into low and high concern for the main H3 interaction, with midpoint responses excluded. Although the revised pooled interaction provides a formal test of the difference between these groups, dichotomisation still discards variation contained in the original five-point scale (MacCallum et al., 2002). The result should therefore be interpreted as evidence of heterogeneity between the defined concern groups rather than as a complete description of how the EV effect changes continuously with climate concern.

Fifth, the total carbon-footprint analysis captures the wider consumption basket but cannot identify the specific pathways through which indirect rebound occurs. A lower total footprint among EV owners could reflect lower transport emissions, different consumption patterns, vehicle-purchase trade-offs or selection. Identifying re-spending would require detailed longitudinal expenditure information.

Sixth, the survey relied on online recruitment and is not established as a strict probability sample. Population representativeness is therefore limited. The distinctive Nordic context—high incomes, comparatively low-carbon electricity and relatively mature EV markets—also limits the extent to which the results can be transferred directly to other regions.

Seventh, important potential confounders remain unavailable or are not included in the present specifications. Commuting distance, employment status, parking availability, home charging, vehicle range, vehicle age, public-transport accessibility and detailed fleet composition could improve comparisons between EV and non-EV households.

Eighth, although H4 is now evaluated with individual interaction terms, a joint significance test and settlement-specific marginal effects, the estimates outside cities remain relatively imprecise.

The lack of a significant interaction therefore means that spatial heterogeneity is not established; it does not demonstrate that the true effects are exactly identical across settlement categories.

Finally, the data reflect the EV market in 2021–2022. Vehicle range, charging infrastructure, policy incentives and the composition of adopters have continued to evolve. Relationships observed during this period may change as EV ownership becomes increasingly mainstream.

4.8 Suggestions for future research

Future research should move from cross-sectional ownership comparisons toward designs that identify behavioural change. The most valuable extension would be longitudinal household data measuring VKT, vehicle fleet, expenditure, and carbon footprint before and after EV adoption. A difference-in-differences design, fixed-effects panel model, or another credible quasi-experimental strategy could control for time-invariant household preferences and establish whether VKT changes within the same household after the switch. Such a design would allow a much stronger direct rebound interpretation.

A second priority is to measure the actual economic mechanism. Household-specific cost per kilometre should include electricity price, fuel price for comparison vehicles, maintenance, taxes, tolls, charging fees, and potentially time cost. Combining these variables with pre- and post-adoption VKT would allow a rebound elasticity to be estimated rather than using ownership as a proxy for cost change. This would also make results more comparable with the conventional fuel-efficiency literature.

Third, future work should model household vehicle fleets explicitly. Key categories include replacing the only ICE vehicle with an EV, adding an EV to a mixed fleet, transitioning to an all-electric multi-car fleet, and downsizing or upsizing vehicle ownership. Vehicle range and home-charging access should be added because they determine which trips can be shifted to the EV. This extension would directly test whether the negative VKT association in the present sample partly reflects selection of lower-mileage households into particular EV configurations.

Fourth, the climate-concern analysis should be strengthened with a pooled EV $\times$ climate-concern interaction. The current dichotomisation discards information from the five-point scale and separate significance tests do not test whether coefficients differ (MacCallum et al., 2002; Gelman and Stern, 2006). A pooled specification could estimate marginal EV effects across the

full concern distribution and test whether heterogeneity remains after accounting for charging access, range, income, and fleet composition.

Fifth, indirect rebound should be decomposed by consumption category. Detailed household expenditure and carbon-footprint data could identify whether lower mobility expenditure is associated with greater spending on aviation, leisure, housing, food, or other categories. The same framework could test desirable rebound by examining whether high EV purchase expenditure temporarily displaces high-carbon consumption. This would directly connect the budget mechanisms discussed by Font Vivanco et al. (2022) and the mobility-consumption trade-offs identified by Ottelin et al. (2024).

Sixth, spatial analysis should move beyond a three-category urbanisation indicator. Accessibility measures such as distance to employment centres, public-transport frequency, road-network travel time, charging density, and service proximity would better represent the mechanisms that create rural car dependence. Linking household microdata with GIS-based accessibility could test whether rebound differs between structurally necessary and discretionary travel rather than between broad settlement labels alone.

Seventh, modal substitution deserves explicit treatment because BEV ownership can change not only car-trip demand but also the allocation of travel across modes (Green and Ostli, 2025). Household VKT could remain stable while car use replaces public transport, cycling, or walking, which would have implications that are not visible in a kilometre-only model. Future work should therefore analyse mode shares alongside VKT where the data permit.

Eighth, future research should replicate the analysis in regions with different electricity mixes and EV policies. A positive VKT rebound has different climate consequences where electricity is generated from fossil fuels than where marginal electricity is low-carbon. Market maturity also matters: early-adopter selection may decline as EVs become the default vehicle technology. Repeating comparable models over time would reveal whether the EV-VKT relationship converges toward conventional-car travel as range, charging, and adoption expand.

Finally, future work should strengthen reproducibility and reporting. Regression tables should be exported directly from statistical software with model N, confidence intervals, exact variable labels, and specification notes. Analytical code should define units and sample restrictions in one place, and figures should be generated from the same cleaned data used for estimation. A

reproducible workflow is particularly valuable for multi-country household datasets because subgroup restrictions and recoding decisions can otherwise be difficult to trace.

These suggestions follow directly from the gaps identified in the literature and the limitations of the present analysis. The next step for EV rebound research is not simply to add more cross-sectional comparisons, but to identify when, why and for whom lower-cost electric mobility changes travel, modal choice and the rest of household consumption.

5. Conclusion

The purpose of this thesis was to examine whether EV ownership among car-owning households in Denmark, Finland, Iceland, Norway and Sweden is associated with patterns consistent with a direct driving rebound, and whether this relationship varies with climate concern and degree of urbanisation. The study also examined whether EV ownership is associated with differences in total consumption-based carbon footprint per capita.

Four main conclusions emerge from the analysis. First, H1 is not supported. EV ownership is negatively associated with annual VKT per capita ($\beta = -0.1197$, $p = 0.003$), corresponding to approximately 11.3% lower VKT after adjustment for income, household size, settlement type and country. The positive travel response expected under a simple direct-rebound mechanism is therefore not observed in this sample. Because the analysis is cross-sectional, this result should be interpreted as an association rather than evidence that switching to an EV causes households to reduce driving.

Second, H2 is supported. EV-owning households have an approximately 20.6% lower total consumption-based carbon footprint per capita than comparable non-EV car-owning households ($\beta = -0.2309$, $p < 0.001$). Since the outcome includes emissions associated with the wider household consumption basket, the result indicates that broader consumption does not eliminate the observed footprint difference. However, the analysis cannot identify whether this difference is caused by EV technology itself, household lifestyle, selection into EV ownership or expenditure trade-offs.

Third, H3 is supported. The EV–VKT association differs significantly between low- and high-climate-concern households. Among respondents with low climate concern, EV ownership is associated with substantially lower VKT ($\beta = -0.3397$, $p = 0.013$), while the EV coefficient is close to zero among respondents with high concern ($\beta = 0.0048$, $p = 0.921$). The pooled interaction between EV ownership and high climate concern is statistically significant ($\beta = 0.3478$, $p = 0.020$; $F(1,4467) = 5.44$, $p = 0.0198$). This shows that climate concern is associated with heterogeneity in the EV–VKT relationship, although the cross-sectional design does not establish a causal mechanism.

Finally, H4 is not supported. Town/suburban and rural households have significantly higher VKT than city households, but the EV $\times$ settlement interaction terms are not statistically significant. The joint interaction test also provides no evidence of spatial heterogeneity, $F(2,5790) = 0.49$,

$p=0.614$. The results therefore distinguish high baseline rural mobility from a stronger EV-related rebound: rural households drive more, but the association between EV ownership and VKT does not differ significantly across settlement types.

Overall, the findings support a context-dependent rather than universal interpretation of EV rebound. In this Nordic cross-section, EV ownership is associated with lower VKT and a lower total consumption-based carbon footprint, while the EV–VKT relationship varies with climate concern but not significantly with degree of urbanisation. The results also show that EV-related mobility cannot be understood from operating cost alone; household characteristics, environmental attitudes, spatial conditions and selection into EV ownership are likely to shape the observed relationship.

The main limitation is the cross-sectional design, which prevents causal identification of behavioural change after EV adoption. Future research should therefore use longitudinal household data, actual changes in operating cost, detailed vehicle-fleet information, charging and range characteristics, and category-level expenditure data. Such approaches would allow direct and indirect rebound mechanisms to be identified more precisely and would clarify whether the heterogeneity observed in this study reflects behavioural responses or pre-existing differences between households.

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