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Measuring the equity impacts of government subsidies for electric vehicles

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ABSTRACT

A shift to electric vehicles (EV) is seen as one of the main methods to decarbonise the transportation sector. However, issues have also been raised regarding charging infrastructure, EV reliability and range, as well as the battery environmental and social credentials. Notwithstanding governments, intergovernmental organisations, and research entities have ploughed ahead to promote this transition, but the challenge is the uptake and public acceptance. Grants and financial subsidies have been developed to facilitate this shift. Our study investigates the characteristics of the private EV household charger population using a regression model and spatial analysis to determine the influences of income, car ownership and economic status on EV take up rates. Data on the installation of EV household chargers are used in this paper as a proxy for EV ownership, due to data limitations. The results indicate that 1) urban areas are more likely to see higher concentrations of EV ownership, 2) an income and equity gap exists between those that have adapted electric mobility. This finding is very important because it suggests that lower income categories may have a financial barrier to shifting to EVs.

1. Introduction

Ireland, like many other countries, is struggling to determine how to reduce emissions from road-based transport. One of the main policies that has been enacted by the Irish government is to encourage the electrification of the private car fleet. Foley et al. [1] demonstrated that if 10% of the private car fleet in Ireland is converted to electric vehicles (EVs), it could result in considerable emissions savings. In the recent Climate Action Plan published by the Irish government, targets for almost a million electric vehicles by 2030 were announced [2]. The Irish government have an answer similar to other countries and, like many others, intend to stimulate the adoption of EVs by using mainly financial incentives.

The uptake of EVs is highly dependent on customers' purchasing choices which the government seek to influence by offering a suite of supports. The supports include financial and non-financial incentives, regulatory measures, charging infrastructure development and raising awareness [3,4]. At the same time, measures are taken to disincentivise fossil-fuelled vehicles. In Ireland, EVs receive government support through the SEAI Grant Scheme on purchase, vehicle registration tax relief and toll reduction of approximately up to €15,000 per vehicle [5]. These supports are applied to all new vehicle purchases with a limit on the tax breaks based upon the cost of the EV. The vehicles are also eligible for the lowest motor tax band and are exempted from fuel excise or carbon tax. In addition, the government offers a grant of up to €600 for the installation of home charging points for EVs registered from 2018 onwards. The subsidies for private and commercial vehicles purchases are likewise available across Europe and beyond [6] and found to have a significantly positive effect on EV adoption rates, however subject to demand elasticity [7]. Other policy incentives, including scrappage schemes, interest-free loans, access to bus lanes, speed limit changes, parking incentives or emission linked congestion charging, applied in some European countries are also considered for implementation in Ireland [4]. The government also addresses the consumers need for new fueling arrangements by

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providing public charging infrastructure. The expansion of the charging network is an important predictor of EV market share [7]. However, continuous governmental support for public infrastructure development [2] does not pair with the targets of the growing EV fleet in Ireland. As a result, current EV owners must rely primarily on home charging which accounts for 80% of charging sessions [4].

The Irish government has very ambitious targets for EVs, and by 2030 they aim to have 840,000 passenger cars in the Irish fleet [2]. In 2019, the Irish government published an evaluation of the financial supports and compared them against the benefits of reduced emissions and air quality improvements. They found benefit-cost ratios of between 0.144 and 0.203 [5]. This would call into question the wisdom of the use of public funds to support EV purchases. However, these findings are not unique to Ireland, and similar policies are used internationally. In 2020, EVs made up less than 5% of new car sales [8]. This shows that Ireland is in a slow transition to electrify its private car fleet and is slightly higher than the EU average of 3.5% [9].

Research addressing the transition to EVs is extensive and has focused on a wide variety of technical and social issues. Regarding the first, for instance, Zhang et al. [10], discuss the advantages and barriers for the use of thermal management methods of lithium-ion batteries in EVs, while Xu et al. [11], investigated EVs' batteries aging and degradation. Others have explored how the deployment of EVs, in tandem with the large-scale penetration of variable renewable energy sources, generates technical challenges for power grid balancing. Meanwhile, a number of papers have studied the impacts of EVs in terms of greenhouse gas emissions and how this may cause new and prevalent engineering problems [12–14]. Research regarding the social aspects of EVs has focused on themes ranging from the safety and noise implications of EVs to range anxiety and economic barriers [15,16]. Unlike previous studies, therefore, the research presented in this paper examines the factors that have influenced the installation of an application for grants for household EV charging points. In recent years in Ireland, the number of EV purchases has augmented, increasing, in consequence, the number of household charging point installations. Our study seeks to determine how income, deprivation, car ownership, and trip characteristics in areas of Ireland influence the density of these household charging points. This is the novelty of the work, and is unlike previous other work, which has focused on charging optimization [17], battery [18]and fuel cell performance [19], societal cost [20] and consumer acceptance [21], emissions and energy [1], and vehicle to grid opportunities [22].

The main motivations for this research were to examine what relations exist between income and affluence levels and the propensity to own an EV. A key policy question in the rollout of EVs and other low emission technologies is the equity of affordability and how policy could be used to ensure a just transition. Ireland, like many other countries, is grappling with this policy question, and our research aims to examine the extent to which this problem exists in Ireland. The research in this paper adds to the body of work published in this area as it specifically looks at household charging locations in Ireland as a case study for other countries. Focusing on these locations enables the research to examine the density of households in geographic areas and correlate higher densities with other variables such as income and affluence. A deprivation index is utilised in the study, and this contribution allows the researchers to examine potential equity impacts of the switch to electric mobility. The research can aid energy policymakers on how to best direct state aid for switching to electric mobility and ensure a just transition to a greener economy.

The paper contains five sections. Section 1 introduces and puts the main motivation for the work in context. Section 2 presents a literature review of similar work in the field. Section 3 details the methodology. Section 4 discusses the results. Section 5 concludes with the key findings and recommendations.

2. Literature review

2.1. Equity and income impacts on EV uptake

The concepts of income and political classes impacts upon EV purchase was examined by Sovacool et al. [23]. In their study, the team examined preferences across five European countries and found that those with higher income levels and living in urban areas had a greater interest in purchasing EVs. Similar results were obtained by Kumar and Alok [24], in their research, after an extensive overview of the literature, the team identified that income, higher level of education and multiple car ownership are all key elements that impact upon EV purchase. Others [25,26] have reported that young women with high income are more prone to purchase an EV. Opposite results are revealed by Sovacool et al. [27], suggesting that men, with higher levels of education, having full-time employment, especially working in civil societies and academia, and below middle age (30–45), are the most likely to purchase an EV. Whilst others have identified that long-distance commuters [28] and people driving long mileage [29,30] are keen EV adopters.

Wells [31] found that EV adopters are often wealthy, which may contribute and exacerbate important aspects of exclusion, inequality, and poverty. A similar perspective is offered by Sovacool et al. [23], when they note that electric mobility can contribute to the weakening elements of distributive justice by making this service "*accessible only to the rich … reinforcing* [in consequence] *exclusion and elitism in national planning*". Indeed, other studies support this view and note that mobility policies do little to address this issue and caution that without an intentional focus on equity [32]; may in fact, increase inequality [33]. Injustices, however, are not limited to electric mobility but instead, they expand across all sectors of mobility, ranging from rail and aviation services to car and walking/trips [34].

2.2. Rebates and equity

Globally, policymakers have introduced financial purchase incentives to foster the growth of EV markets and, with this, improve air quality, meet climate target goals and lower energy consumption [35]. For instance, the government of Ireland has promoted the adoption of EV vehicles through grants and rebates up to €5000 [36]. However, regardless of these incentives, barriers for uptake may persist for low-income consumers. For instance, Hardman et al. [35] and Snelling [37] note that to acquire these incentives, first, consumers need to purchase the vehicle, presenting a critical barrier for those with limited financial resources or those who lack access to credit. On the same vein, Ju et al. [38] argue that for lower-income consumers, rebate programs for EVs can become even less accessible if the refund amount does not increase according to income. Indeed, evidence indicates that wealthier consumers are not only more likely to adopt these vehicles [39] but also, that incentives are not reaching nor designed for the intended consumers due. DeShazo [40] explains, due to eligibility restrictions, salience of mechanisms in consumer decision making and the impact of rebates across consumers and producers. However, rebates that benefit the wealthier are not exclusive to EV policies, research indicates that in many cases, these instruments although are thought to aid the middle class and vulnerable groups, in reality, the benefits are often perceived by the wealthy [41].

Supporting these views, Rubin and St. Louis [42] and Ju et al. [38]

assessed California's Clean Vehicle Rebate Project (CVRP) with both studies showing similar results. They found that the CVRP program generated greater benefits to wealthier neighbourhoods, with higher levels of education and with fewer people of colour and Hispanics. Indeed, research supports these findings and suggests that wealthy consumers, those able to buy EVs at their full retail price, may utilise the most of the incentives [31,43]. The previous does not mean that incentives are unnecessary, in fact, research indicates that such instruments will still be needed for a while if we want to transition to a low-carbon future, however, these do need to be better designed [27,35]. Ju et al. [38] suggest that equity-related designs programs must go beyond income cap and income-tiered rebate amounts if policymakers want to make these programs "*more accessible to those who could benefit the most*". Indeed, policymakers and regulators are beginning to consider concerns. For instance, New England has noted that access and equity are key priorities in the design of electric vehicle programs. Therefore, the state government has now rolled out incentives with specific carve-outs for lower- and moderate-income residents with a $2.5 million dollar program [44]. Whist the California Air Resources Board [45], approved a $533 million plan to fund clean car rebates. One of the most impactful changes from this regulation is that the state will now restrict rebates to qualifying vehicles with a retail suggested price of $60,000 or less.

2.3. Price as a barrier for uptake

Shifting attention away from rebates, research indicates that the most common barriers impeding the uptake of EVs are those related with range, charging infrastructure and price [31,39,46,47]. However, given the focus of our study, we will only centre in the last, since this feature exacerbates exclusion from vulnerable and low-income communities to advance the uptake of EVs. For instance, Noel et al. [48] and Berkeley et al. [49] note that a common barrier for the uptake of EVs is high purchase price. This is further corroborated by Silvia and Krause [43], when they note that EVs are considerably more expensive than similar gasoline-powered vehicles. For instance, a Chevrolet Volt and Nissan Leaf prices are between $15,000 to $20,000 more expensive in comparison to gasoline-powered vehicles. Prices may increase if users want to install home charging stations (Level 2 residential EVSE) which adds an additional cost of up to $2000 [50]. In fact, some argue that these additional costs represent another important barrier for their uptake [43,51], particularly for those who do not own an apartment and live in rental accommodation [28,52].

Preferences and intentions to purchase EV are also closely aligned to those in a more privileged position. For instance, Ensslen et al. [53] examined EVs' purchasing intentions in France and Germany, their results show that those with higher level of income and multiple car ownership are more likely to consider purchasing an EV. An outdated study [54] found similar results for the UK, where those with higher income are more likely to consider EVs as their second vehicle. EVs are also perceived as a status sign that symbolise luxury in some countries of the Nordic region as illustrated by Refs. [27,55]. Whilst in China, EVs are perceived as a luxury vehicle and is "*thus fast becoming cemented within the Chinese consumer imagination* [56]". EV adopters fell in the same category, for instance, Sovacool et al. [52] reviewed [57–60] and found that in Canada, USA, Norway and Sweden respectively, adopters of electric vehicles tend to have higher income compared to the "normal population". To close this gap, Hardman et al. [35] notes that not only campaigns of promotion and awareness must aim all socio demographic groups, but also economic incentives for the less privileged groups ought to be designed with longevity in mind.

What this section illustrates is that at least at the moment, the deployment of EV vehicles is not only aiming to the wealthier sectors, but also, the benefits that emanates of these are been perceived by the same group. Changing the current paradigm is not an easy task; however, motivations to mass adoption may change if as suggested by Noel et al. [39] and Zarazua [61], policies centre on the status and technological elements of EVs rather than on the environmental benefits.

The research presented in this paper builds upon the previously published in this field. It adds to the body of work by interrogating the relationships between density of household charging points, used as a proxy of EV ownership, and income/affluence. The distribution of EV ownership within society reflects the influence of policy measures introduced by the government. Hence, analysing the profiles of EV owners shed light on the distributive justice of governmental support. The results of this study provide a valuable contribution by examining the equity impacts of EV support grants in Ireland.

3. Data and methods

3.1. Data

In Ireland data collected from the census is broken down into a number of geographical regions. These regions vary in size the largest being provinces (4) and the smallest being Small Area Population Statistics (SAPS) (18,641) [59]. Graphical area used for the majority of the analysis presented in this paper was at the electoral district level of which there are 3409 in the Republic of Ireland. EV charging points have been installed in just under 1400 of these electoral districts in Ireland resulting in approximately 40% of these areas having one or more household charging points installed.

The data that was used in this study was provided by the Sustainable Energy Authority of Ireland (SEAI) and relates to household EV charging points installed between 2018 and the beginning of 2020. Within two years 4611 home chargers were installed, corresponding to 99% of EVs newly registered in the same period in Ireland [8]. The data that was provided contains information on the electoral district in which the charging point has been installed and details on the model of EV and the year in which the dwelling, where the charging point was installed, was constructed. The data obtained from SEAI and the data on household characteristics, income and deprivation index values extracted from the Census of 2016 [62], provide the foundations of the research conducted in this study. The charging location data was used in leu of detailed EV ownership data as the geographical information of EV owners is not available in Ireland. In this context, EV charging point data is used essentially as a proxy of EV ownership.

3.2. Methods

The research presented in this paper uses two main research methods. The statistical modelling was conducted using linear regression modelling and ordinary least squares (OLS) regression modelling. The linear regression models are used to examine the relationship between a dependent variable and an independent variable. The OLS models take a form of a dependent variable compared against a series of independent variables. These methods have been widely used in the literature and as such, were deemed an appropriate way to examine the data gathered [63–66]. We have applied multiple regression as an explanatory tool to identify the relative importance of variables in "predicting" the dependent variable. The explanatory variables with larger regression coefficients were flagged as having a greater influence on the

Table 1
Description of variables (Dublin Model).

	Mean	Std. dev	Min	Max
Dependant Variable				
Number of household charging points	5.45	7.42	0	66
Independent Variables				
Means of travel to work				
Walk	527.09	504.11	24	4780
Bus	389.15	397.90	9	4195
Rail	187.07	277.90	0	2752
Drive	879.21	1086.19	65	10,845
Drive - Passenger	326.68	462.70	10	4423
Van	58.75	80.98	2	879
Working from home	45.72	41.43	1	322
Travel time (to work)				
Less than 15 min	594.95	659.63	80	7189
15–30 min	823.54	770.83	97	7722
30–45 min	605.08	568.40	79	5546
More than 90 min	45.10	71.25	3	838
Cars per-household				
One car	627.13	523.05	54	5235
Two Cars	400.04	478.04	6	4508
Four or more cars	17.12	19.85	0	149
Income	€55,106	€15,443	€25,627	€105,943
Deprivation Index	−0.489	9.31	−25.89	16.85

dependant variable [66]. In all of the models examined in this paper, the dependent variable is always the number of household charging points in each electoral area. We have run linear regression models to study how the deprivation index and income influence the number of charging points, and the outcomes are presented in section *4.2 Equity and income impacts*. The OLS models estimated in this research examined factors affecting the dependent variable and are detailed in Tables 5 and 6 in section 4.3 *Regression analysis*. To identify the OLS models with the best explanatory capacity, we used stepwise regression to remove the independent variables with little effect on the dependent variable.

In our study, two sets of variables are examined, those applied in the Dublin area and those in Ireland excluding Dublin. Tables 1 and 2 detail the descriptive statistics of the variables examined. The independent variables examined in Dublin Model and Rest of Dublin Model differ as some variables were found to be statistically significant in one region but not in the other. The data provided in Tables 1 and 2 pertain to the numbers of people or households in each of the census areas examined that exhibit the characteristics listed in these tables. Descriptive statistics portray heterogeneity of

Table 2
Description of variables (Rest of Ireland Model).

	Mean	Std. dev	Min	Max
Dependant Variable				
Number of household charging points	0.92	2.65	0	46
Independent Variables				
Profession				
Employers and manager	50.90	105.13	0	1629
Higher professional	22.15	54.08	0	1072
Non-manual	68.91	140.98	0	1891
Manual Skilled	37.62	59.07	0	1022
Semi-skilled	35.81	63.92	0	932
Agricultural workers	2.91	4.57	0	73
Means of travel to work				
Bus	60.83	105.01	0	1661
Drive	297.81	547.37	11	8232
Drive - Passenger	150.65	276.15	0	4106
Van	35.43	43.16	0	796
Travel time (to work)				
Less than 15 min	247.75	465.59	2	5795
30–45 min	102.69	195.27	2	3344
45–60 min	33.50	72.58	0	1501
Cars per-household				
Two Cars	142.08	236.75	2	3451
Four or more cars	8.07	11.07	0	164
Income	€43,452	€10,269	€14,901	€101,740
Deprivation Index	−5.47	5.80	−35.71	14.18

data by referring to a minimum and maximum number of people or households in each category, an average number of them (mean) and variation among the values (standard deviation).

4. Analysis of household charging locations

This section of the paper presents the findings of the research conducted. The analysis starts by examining the macro level trends across the country and then examines the relationships between equity/income and EV ownership. The final set up of analysis determines the statistical relationships between a number of socio economic and geographic attributes and the propensity to adopt EVs.

4.1. Locations of charging stations

Table 3 details the distribution of household charging points across the four provinces of Ireland and Dublin, the capital of the country and the largest population centre. The population and population density in each of the regions is also contained in Table 3. A comparison across the data show that Dublin with the highest and most dense population has the largest number of household charging stations. Table 4 shows the distribution of the age of the house that the charging point is in and data from the 2016 Census on the age profile of house in Ireland. Comparing the two data sources it shows little variation with the exception of the 2011–2020 category. This difference is due to the fact that the Census was conducted in 2016 and therefore is missing four years of data on new house builds.

Fig. 1 displays the distribution of the number of charging points in each of the 1400 electoral districts in Ireland. The range varies from 1 to 66 charging points in one of these districts with a mean of 3.324 and a standard deviation of 5.127. The distribution shows that the number of charging points is heavily skewed towards one or two per electoral area and this is discussed in more detailed in the following section.

Table 5
OLS estimations for Dublin.

Variables	Dublin
Constant	3.681 (1.517)**
Means of travel to work	
Walk	-.009 (.003)***
Bus	.010 (.002***
Rail	.010 (.002)***
Drive	.012 (.003)**
Drive - Passenger	.015 (.002)***
Van	-.050 (.009)***
Working from home	.022 (.013)**
Travel time (to work)	
Less than 15 min	-.008 (.003)**
15–30 min	-.006 (.002)***
30–45 min	.010 (.003)***
More than 90 min	-.031 (.011)***
Cars per-household	
One car	-.006 (.002)***
Two Cars	.023 (.003)***
Four or more cars	.027 (.024)***
Income	.018 (.046)***
Deprivation Index	.160 (.002)***
Observations	322
R-squared	.884

Standard error in parenthesis, ***p < 0.01, **p < 0.01, *p < 0.1.

4.2. Equity and income impacts

This paper seeks to examine these phenomena by examining what impact hiring comes and relative levels of affluence have upon the concentrations of charging points in Ireland. To do this a

Table 3
Distribution of private EV charging points.

Province	Number of household charging points		Population – Census 2016		Population density per (km^2)
	N	%	N	%	
Connacht	361	7.8	550,688	11.6	31.1
Leinster (excluding Dublin)	1393	30.2	1,287,044	27.0	68.2
Dublin	1762	38.2	1,347,359	28.3	1461.3
Munster	966	20.9	1,280,020	26.9	51.9
Ulster	129	2.8	296,754	6.2	36.7
Total	4611	100.0	4,761,865	100.0	

Table 4
Number of charging stations by the year housing was built.

Year housing built	Housing with household charging units		Housing as per the 2016 Census of Ireland	
	N	%	N	%
Before 1919	190	4.1	141,200	8.9
1919 to 1945	166	3.6	109,668	6.9
1946 to 1960	274	5.9	126,107	8.0
1961–1970	289	6.3	116,041	7.3
1971–1980	557	12.1	213,473	13.5
1981–1990	470	10.2	171,044	10.8
1991–2000	888	19.3	240,811	15.2
2001–2010	1169	25.4	431,763	27.3
2011–2020	608	13.2	33,436	2.1
Total	4611	100.0	1,583,543	100.0

Table 6
OLS estimations for Ireland (excluding Dublin).

Variables	Rest of Ireland
Constant	.073 (.198)**
Profession	
Employers and manager	.006 (.002)***
Higher professional	.005 (.001)***
Non-manual	-.004 (.002)***
Manual Skilled	.005 (.002)**
Semi-skilled	.015 (.004)***
Agricultural workers	-.013 (.005)***
Means of travel to work	
Bus	.002 (.001)***
Drive	.014 (.004)***
Drive - Passenger	.003 (.009)***
Van	-.016 (.011)***
Travel time (to work)	
Less than 15 min	-.001 (.000)***
30–45 min	-.003 (.001)***
45–60 min	.010 (.004)***
Cars per-household	
Two Cars	.015 (.002)***
Four or more cars	.017 (.006)***
Income	.026 (.021)**
Deprivation Index	.010 (.011)**
Observations	3087
R-squared	.844

Standard error in parenthesis, ***p < 0.01, **p < 0.01, *p < 0.1.

deprivation index which is derived from the Census was used to measure relative affluence/deprivation. This deprivation index uses factors such as social class, education levels, employment and household types to derive an overall index [67]. Negative and low values are used to indicate areas in Ireland's that are said to be deprived whereas the positive values represent the more affluent parts of the country. In the following analysis income is also examined to see what impact that has upon concentrations of charging stations. It should be noted that income is not included in the deprivation index, so it is examined in isolation in this section of the paper.

Fig. 2a provides a distribution of the number of household charging points per electoral district as examined in this research. Almost half of the electoral districts examined had only one of these charging points. Each dot on this map represents four household charging points. The concentrations on the map represent each of the five cities in Ireland with the largest concentration of charging points on the right-hand side of the map where Dublin is situated. Fig. 2b shows the breakdown of the deprivation index across Ireland and visually comparing the two maps one can see that the concentrations of charging points tend to be in the more affluent parts of the country.

Fig. 3a and b provide the same detail as presented in the previous maps but it zoomed in to the County of Dublin to demonstrate a similar trend as seen in Fig. 2a and b. Fig. 4 Presents the results of a linear regression between the deprivation index and the number of charging points. The relationship modelled was found to be statistically significant (at the 99% confidence level) and demonstrates a positive relationship between higher values on the deprivation index and the number of charging points. This analysis confirms what is seen in Fig. 2(a and b) and 3 (a,b) that those living in more affluent areas are more likely to have a household EV charging station installed.

Average household income in each of the electoral districts is examined to determine if a relationship similar to that of the deprivation index exists with income. Fig. 5a and b measure the relationships between charging locations and average household income across Ireland. Fig. 6a and b examine the same relationship but zoomed in to County Dublin in order to appreciate the relationship between the two variables visually. The trends in both sets of figures demonstrate, similar to those that measured deprivation, a relationship between the areas of higher income and the number of charging stations in those areas. A linear regression was also conducted between the number of charging stations and the

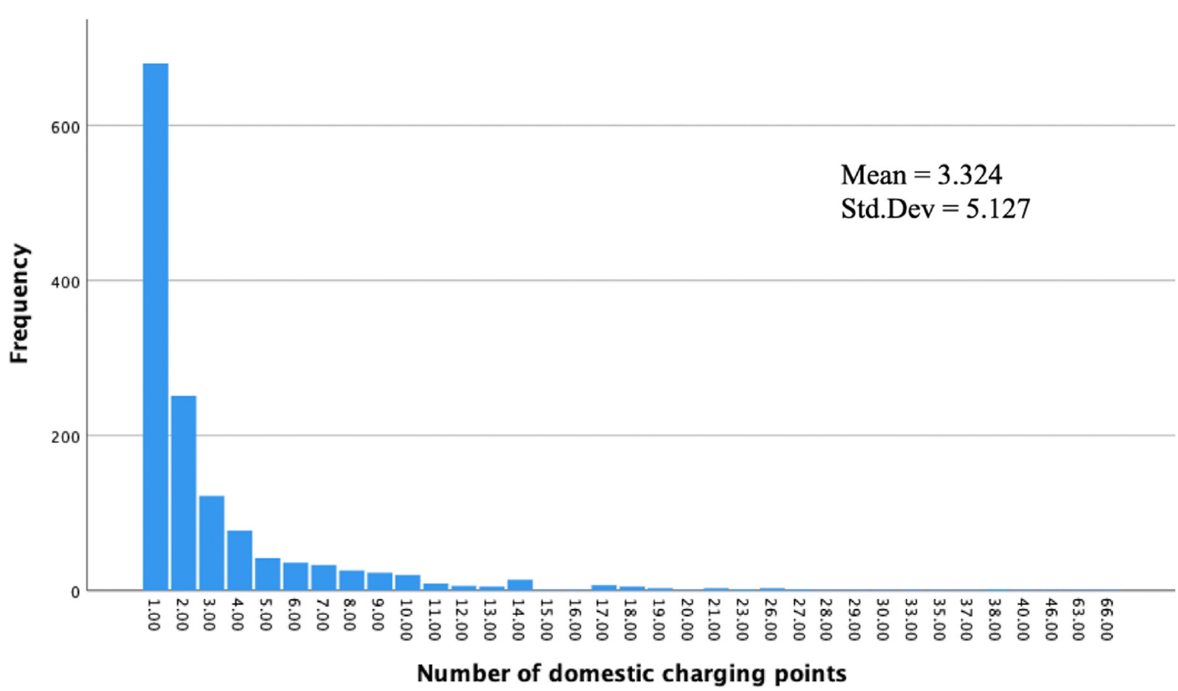


Fig. 1. Distribution of household charging points.

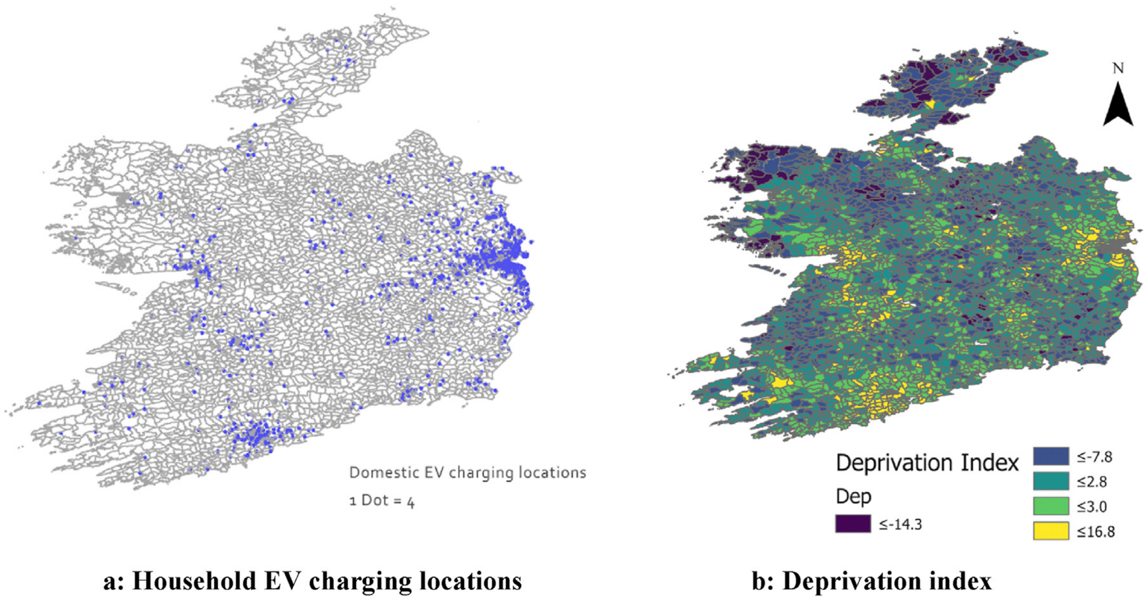


Fig. 2. a: Household EV charging locations. b: Deprivation index.

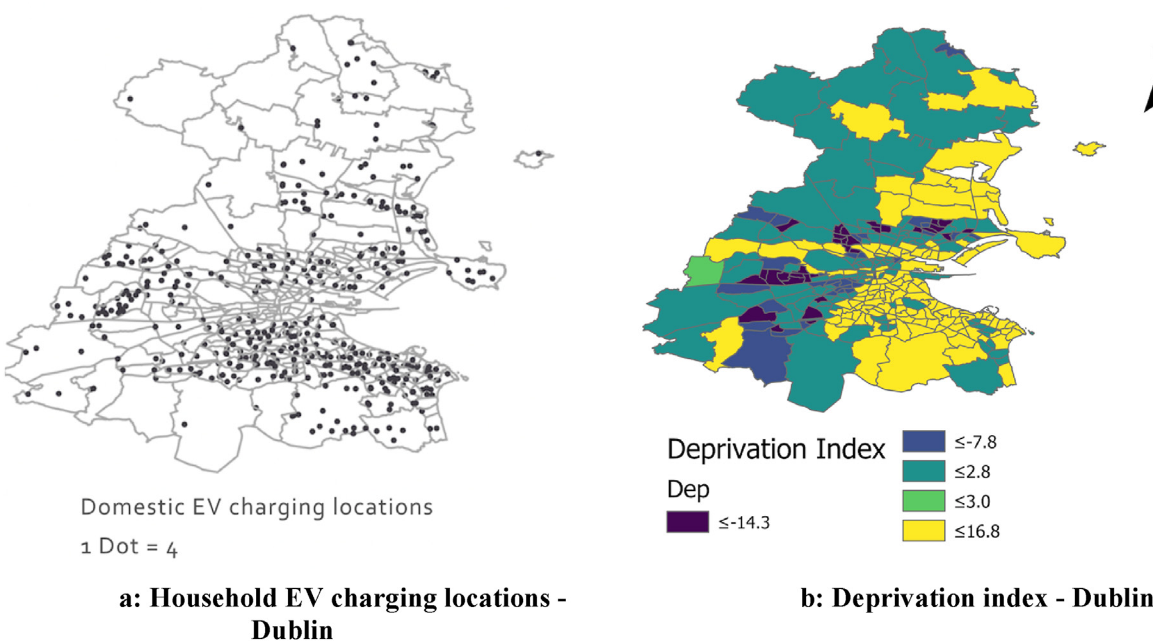


Fig. 3. a: Household EV charging locations - Dublin. b: Deprivation index - Dublin.

average household income per electoral district and the results of which can be found in Fig. 7. The relationship between these variables was found to be positive and statistically significant at the 99% level.

4.3. Regression analysis

This section of the paper presents the results conducted of the OLS regression analysis. The analysis in this action is split between Dublin and the rest of Ireland similar to the analysis presented in the previous section. The decision to split the analysis between the two regions was done due to a number of reasons. The first reason was the high concentration of charging points in Dublin compared to the rest of Ireland, that is when a full model was run of all of the data (with that segregation) very few of the variables examined were found to be statistically significant and finally the differences in transportation options in Dublin compared to the rest of Ireland and the residential densities as discussed previously.

Table 5 contains a number of independent variables that were found to be statistically significant when estimated in an OLS model with the number of charging points as the dependent variable for Dublin. The main variables that were found be significant related mainly to means of travel to work, travel time to work and the number of vehicles per household. The results show that areas with

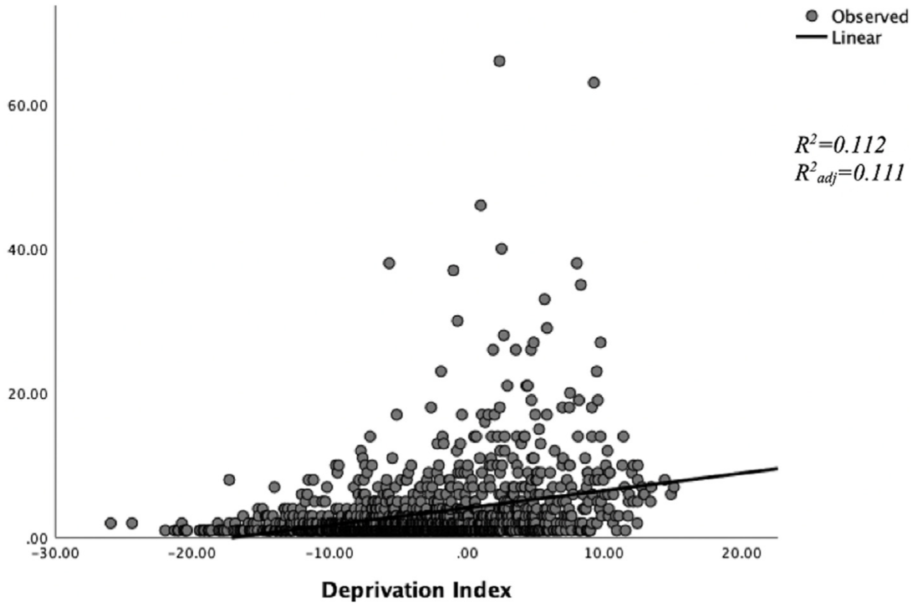


Fig. 4. Linear regression of depravation index and number of household charging points.

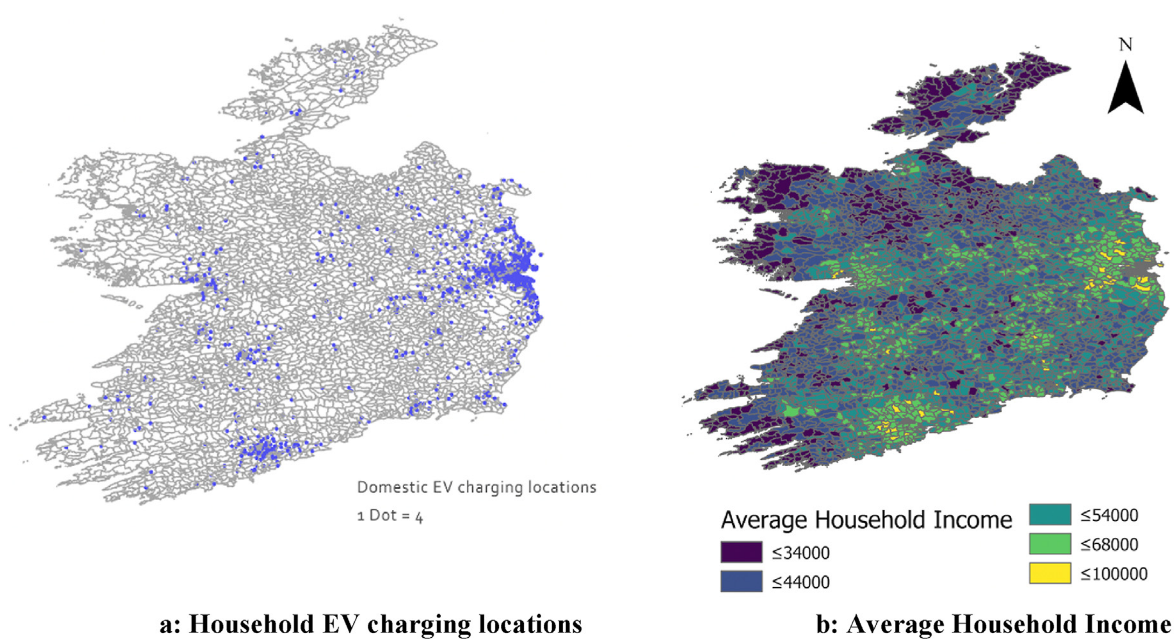
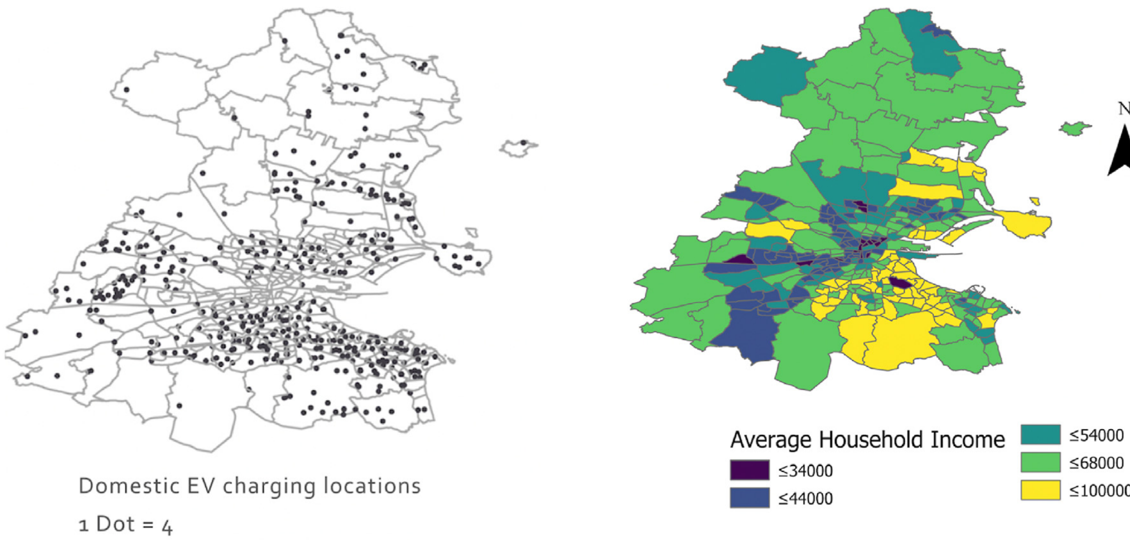


Fig. 5. a: Household EV charging locations. b: Average Household Income.

high levels of domestic charging points are more likely to have greater numbers working from home, driving to work or as a passenger in a car. The results also show a negative relationship between areas with high numbers walking to work and driving to work using a van and the number of charging points per area. The estimate also showed that those areas with an average travel time with of 30–45 min s were more likely to have a larger number of charging stations. Car ownership is also found to have a statistically significant relationship and those living in areas with two or four or more cars were, unsurprisingly, in areas with a higher density of charging points. The final two variables examined in the model presented in Table 5 demonstrates a positive relationship between income and deprivation and the density of household charging points. These relationships concur with those found in previous sections of the paper in that areas that are more affluence with higher levels of income are more likely to have a greater density of household charging points.

Table 6 details the independent variables that were found to be statistically significant in an OLS model with the number of household charging points as the dependent variable for Ireland excluding Dublin. In this model a larger number of variables were found to be statistically significant and interestingly profession and travel time to work were found to show a strong relationship. The results showed that those areas would have larger numbers of



a: Household EV charging locations - Dublin **b: Average Household Income - Dublin**

Fig. 6. a: Household EV charging locations - Dublin. b: Average Household Income - Dublin.

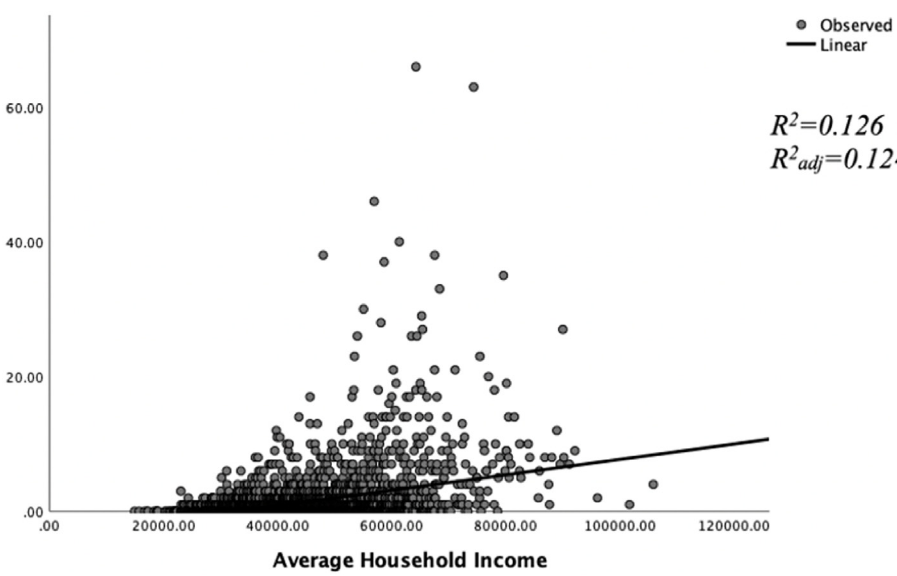


Fig. 7. Linear regression of average household income and domestic charging points.

individuals in the higher professional working groups were shown to have a positive relationship. The results for travel to work showed a similar relationship to that found in the Dublin model in that areas with large numbers of drivers and passengers in cars had a positive relationship with the dependent variable and a similar pattern was also found for travel time. Car ownership in this model is also found to have similar relationship with areas with larger numbers of cars per households more likely to have a higher density of charging points. The income and deprivation variables also showed that areas with higher levels of income and higher affluence were more likely to have greater numbers of household charging points.

5. Conclusions and policy implications

Our paper presents new findings on the equity and income impacts of EV adoption in Ireland. Our study is one of the few to examine the equity impacts of EV adoption rates using a national indicator for affluence and in doing so builds upon the previous work in this field. The paper also examines the locations of household charging points that have received a state grant to cover the majority of the cost of the installation. Our findings demonstrate a correlation between high income and affluent areas and the density of household EV charging points. This is perhaps not that surprising given the high costs of purchasing a new EV compared to a non-EV. The research also shows that the areas with higher numbers of EV charging points also have higher levels of car ownership, suggesting that the EV may be the second or third car in the household. The analysis also suggests, specifically in Dublin, that areas with higher levels of charging points are also areas with higher levels of public transport usage.

Our research challenges the current model of providing support grants for household charging installations. Moreover, our findings suggest grants are most prominent in affluent, urban areas with high levels of public transport usage and/or availability. Similarly, Carroll et al. [68] has shown that there are significant pockets of forced car ownership in Ireland and that in these pockets, mainly in rural areas, there are considerably fewer public transport alternatives. Based in our results, we suggest that current grants for EVs privilege high-income people. Therefore, we argue that the engineering technical grid enhancements will only be affected in wealthy neighbourhoods, leaving low-income and other marginalised groups behind towards the transition to an EV future. As Schwanen [69] simply put it, EVs '*remain luxury goods*'.

The findings of this paper add to the policy debate in this area. They show that in Ireland, a country with low take up rates for EVs, the current policy seems to be only taken up by those in more affluent areas with higher incomes. This has the potential of having an impact upon equity and just transition; as if the price of traditional fuels increase, such policies could have a disproportionate impact upon those living in deprived areas with lower income levels. Gapping this equity gap is an area requiring further research into what policies could be enacted to mitigate against this disparity.

Some alternative policies having a high impact on the adoption of EVs but a reduced adverse effect on social equity are being discussed for potential implementation in Ireland and are currently offered by some governments [4]. For instance, free-interest loans for a new EV purchase, already available in Scotland, or other plans allowing for a longer repayment period, give customers with low upfront capital access to the cheaper running cost of EVs and other incentives. Alternatively, grants for commercial vehicles, which tend to have a higher turnover, can facilitate the development of the second-hand market and increase EVs' affordability. A grant scheme for taxis and other small public service vehicles was recently (2021) introduced in Ireland. Such initiatives are expected to mature the EV market and bring price parity closer in time through exposure to technology.

However, we argue that none of the policies aiming at private vehicle fleet growth will sufficiently address equity concerns. A growing body of literature [23,68,70,71] points out at various societal problems caused by car dependence, ranging from forced car ownership, lack of travel options and insufficient public transport provision for households without a car to high traffic volumes and congestion affecting users of active travel modes. Only transforming how we travel can reduce transport inequalities. Therefore, it is advisable to increase the support for sustainable and inclusive mobility strategies, such as shifting to walking, cycling and affordable public transport, reducing the demand for travel through compact development and enhancing rural accessibility as envisioned in the governmental plans [72–74].

Author credit

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Declaration of competing interest

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

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