UCD CENTRE FOR ECONOMIC RESEARCH

WORKING PAPER SERIES

2020

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WP20/26

September 2020

UCD SCHOOL OF ECONOMICS
UNIVERSITY COLLEGE DUBLIN
BELFIELD DUBLIN 4

Attitudes to Renewable Energy Technologies: Driving Change in Early Adopter Markets

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Abstract: This paper explores the motivations behind the adoption of key renewable energy technologies in an early adopter market. Notwithstanding their social benefits, uptake of electric vehicles, heat pumps, and solar photovoltaic panels remains low, necessitating targeted measures to address this. We conducted a comprehensive survey of a nationally representative sample of Irish households and analysed this rich dataset using pairwise group comparisons and a factor analysis combined with a logit regression model. We found fundamental differences between adopters and non-adopters. Current adopters tend to be younger, more educated, of higher socio-economic status, and more likely to live in newer buildings of generous size than non-adopters. Environmental attitudes are an insufficient predictor of uptake - whilst non-adopters self-report as being more sustainable, adopters believe that their own decisions impact climate change. Importantly, social processes will be instrumental in future uptake. Word-of-mouth recommendation will matter greatly in communicating the use and benefits of technologies as evident from the significantly larger social networks that current adopters enjoy. Using these insights, policy incentives can be designed according to public preferences.

Keywords: Household survey; technology adoption; heat pumps; solar PVs; electric vehicles; consumer behaviour.

JEL Classification: D1, D9, O3, Q4

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1. Introduction

Electrification of heat and transport through the deployment of heat pumps and electric vehicles (EVs[2]) forms a central part of many countries' strategies to reduce greenhouse gas (GHG) emissions (IRENA, 2018). Significant growth in innovations in electricity with a shift to renewable sources such as rooftop solar photovoltaic (PV) systems means that electricity-based heat and transport alternatives generate much lower carbon emissions (EPA, 2020). EVs, heat pumps, and solar PVs are currently the three fastest growing renewable energy technologies (RETs) in Europe (IRENA and European Commission, 2018). Although these technologies vary in terms of their integration into different European markets and some are further along than others in their stage of adoption, Ireland has experienced relatively low uptake of all three technologies to date and is currently not on target to meet the European Commission's Renewable Energy Directive that mandates that all EU nations must fulfil at least 16% of their final energy needs and 10% of energy use in the transport sector with renewables by 2020 (European Commission, 2020; SEAI, 2020a). There is a known lack of awareness and engagement with energy efficiency programmes in general despite several public incentive programmes (SEAI, 2016). Thus, Ireland serves as a case study for other countries in the early stages of market development for RETs.

Although individual consumers and businesses play a crucial role in driving technological change through their decisions to invest in and adopt energy technologies, better understanding is needed of the human factor in terms of how RETs will be adopted in reality and the policies required to incentivise such sustainable investment decisions (IEA, 2019). Previous research conducted internationally has established that a range of attributes may contribute to the uptake of EVs (Mukherjee and Ryan, 2020), solar PVs (Dharshing, 2017; Islam and Meade, 2013; Nath et al., 2016; Rai and McAndrews, 2012; Robinson and Rai, 2015; Schelly, 2014; SGCC, 2016; Sigrin et al., 2015; Zhai and Williams, 2012), and heat pumps (Burley and Pan, 2010; Hannon, 2015; Michelsen and Madlener, 2012; Owen et al., 2013; Singh et al., 2010; Snape et al., 2015). The primary determinants identified are: (1) direct costs such as upfront costs and financial incentives for adoption such as grants and rebates, (2) spatial and built environment

[2] *Abbreviations:* EV: Electric vehicle; GHG: Greenhouse gas; PV: Photovoltaic; RET: Renewable energy technology; BER: Building energy rating.

factors such as where consumers live, their property type, and relevant technical features of RETs and their compatibility with consumers' household infrastructure, (3) socio-demographic factors like age, gender, educational level, and household income, and finally, (4) behavioural factors such as willingness to pay for RETs, familiarity with technologies, perceived ease of use, self-perceived innovativeness, and general attitudes towards sustainability, risk, and time. We classify these explanatory features into four broad categories for easy reference, namely, costs, spatio-technical features, socio-demographics, and behaviour. See Figure 1 for a detailed list of the main variables underpinning RET adoption.

Figure 1: Determinants of RET uptake

Source: Adapted from Mukherjee and Ryan, 2020

Although the international adoption literature is insightful, both drivers and barriers and the effectiveness of government incentives appear to be context-specific and hence, their impact on RET uptake at best ambiguous (Coffman et al., 2017; Curtin et al., 2009; Egbue and Long, 2012; Mukherjee and Ryan, 2020; Plotz et al., 2014). Specific knowledge of triggers and personal characteristics in markets at an early stage of development for these mature technologies is needed since a lack of understanding of the consumer perspective precludes knowledge of the level and timing of likely adoption at scale and hence the design of targeted policies to accelerate uptake (Mukherjee and Ryan, 2020). This paper aims to contribute to filling this gap especially around our understanding of consumer behaviour, namely, attitudes, individual willingness to try new technologies, motivations behind the purchase and use of RETs, and policy design surrounding boosting uptake in a case study of Ireland.

This work collates primary data from three focus groups, four in-depth interviews, and a large-scale survey of a nationally representative sample of the Irish adult population. The qualitative study provided us with exploratory data on the public perception of EVs, solar PVs and heat pumps in Ireland, which subsequently guided the development of our comprehensive survey questionnaire. This approach to data collection has been previously used in seminal studies in energy technology adoption (Burley and Pan, 2010; Gardner et al., 2011; Higgins et al., 2012; Itaoka et al., 2011; Van Acker et al., 2014). As the main component of this research, our survey was carefully designed based on best practice guidelines from the Pew Research Center and the total survey error framework as proposed in Biemer (2010) (Biemer, 2010; Pew Research Centre, 2020) as well as relevant survey literature (Axsen et al., 2009; Egbue and Long, 2012; Islam and Meade, 2013; Michelsen and Madlener, 2012; Nath et al., 2016; Nayum et al., 2016; Plotz et al., 2014; SGCC, 2016; Sigrin et al., 2015; Zhai and Williams, 2012). It explored detailed behavioural, socio-demographic, and household characteristics as well as the self-reported likelihood that participants would purchase RETs in the future. We subsequently analysed this data using factor analysis, pairwise group analysis and a logistic regression. Overall, the present study is unique due to the inclusion of both actual adoption data as well as a number of self-reported preference measures for three distinct household energy technologies allowing us to compare decision-making and attitudes towards technologies with different costs, functions, and appearances in an early adopter market. The results will help us understand the perceived and real trade-offs associated with investing in RETs and support the advancement of targeted strategies that promote private investment in these goods. Whilst the data is for Ireland, we anticipate that our findings would be applicable to other early adopter countries that need such insights to design their policy mix for RET adoption.

This paper is structured as follows. Section 2 presents our data and methods. Section 3 provides detailed results from the qualitative and quantitative studies. Finally, section 4 concludes with a discussion and policy recommendations.

2. Data and methods

This section describes our data collection process, and data preparation for our subsequent econometric analysis.

2.1 Focus groups and interviews

The initial phase of the research involved three focus groups and four in-depth interviews conducted in March 2018 following best practice guidelines in qualitative methods (Bryman, 2012; Casey and Krueger, 2015). Each focus group lasted 90 minutes and consisted of eight to ten respondents, who were given an incentive of €50 for their time. The groups were led by a trained moderator from the Irish market research agency - Amárach Research - following detailed discussion guides developed by researchers from the UCD Energy Institute, whilst two independent researchers from the UCD Energy Institute observed and took notes to compare insights post-discussion. The three groups consisted of EV owners, solar PV owners, and non-adopters of RETs, respectively. EV owners were sourced from the Irish EV Owners Association Facebook group and PV owners were contacted through Solar Electric's customer database. Since we were interested in exploring the decision-making process involved in adoption, those who had bought a property with the technology already installed were excluded. Non-adopters were sourced from a market research panel wherein a recruiter selected participants based on non-ownership of any RET. The focus groups were not designed to be nationally representative in terms of gender, age, region, or social class as, being a precursor to the survey, this exercise was merely exploratory.

Given the very low incidence of heat pump installation, instead of focus groups, we conducted four in-depth interviews with those who had installed heat pumps (either air source or geothermal) at their property. Participants were sourced from Tipperary Energy Agency's database of heat pump owners. Interviews were conducted via telephone calls that lasted between 30 and 45 minutes.

All narratives were analysed using descriptive and thematic analyses by two independent analysts at Amárach Research and were validated by all researchers present at data collection. Appendix B provides the discussion guides. See Table 1 for an overview of our qualitative study.

Group	Study type	Group size	Location	Age	Socio-economic status	Profile
Electric vehicle owners	Focus group	10	Dublin	Mixed	High	Electric vehicle owners
Solar PV owners	Focus group	10	Dublin	Mixed	Mixed	Have had solar PV installed
Heat pump owners	In-depth interview	4	Tipperary, Westmeath	Mixed	Mixed	Heat pump owners
RET non-adopters	Focus group	8	Dublin	Mixed	Mixed	Non-adopters of RET

Table 1: Overview of focus groups and interviews

2.2 Household survey

The second phase of the research involved granular preference data collection via a nationally representative online survey of the Irish adult population designed by researchers at the UCD Energy Institute and administered by a researcher at Amárach Research in July 2018. The survey collected detailed socio-demographic and household data, risk and time preferences, and attitudes, for instance, towards innovation and the environment[3]. Appendix C provides the survey questionnaire.

A random sample of three groups of roughly 400 was drawn from one of Amárach Research's market research panels, resulting in a final sample of 1,208 individuals.[4] 203 respondents owned some form of RET whilst 1,005 owned none. A demographically representative sample

[3] Discrete choice experiments were also performed to elicit preferences for individual technologies. This is the subject of a separate paper (Meles et al., 2019).

[4] A sample of 1,200 is statistically robust with a +/- 2.83% margin of error at a 95% confidence interval. Thus, there is a 95% chance that two identical surveys undertaken at the same time and with similar people will vary upwards or downwards by 2.83 points. A sample size of approximately 400 is statistically significant for 1.2 million households and therefore we selected the individual RET groups to be that number.

was ensured via stratification on age, gender, region, and social class. Quotas were based on the Central Statistics Office Census 2016 figures. Table 2 provides a summary of the main respondent characteristics. This data was subsequently analysed using pairwise group comparisons as well as an econometric model designed for binary dependent variables in statistical software STATA (StataCorp, 2017). These techniques are well-established in the analysis of survey data (Chesser et al., 2019; Clancy et al., 2017; Leahy and Lyons, 2010; Rai et al., 2016).

Variable	Obs.	Mean	Std. Dev.
1 if male	1208	0.466	0.499
Respondent's age:			
1 if age between 18 and 34 years	1208	0.296	0.457
1 if age between 35 and 54 years	1208	0.383	0.486
1 if age is above 55 years	1208	0.321	0.467
Respondent's highest education obtained:			
1 if secondary or primary	1208	0.418	0.493
1 if third level degree	1208	0.408	0.492
1 if master's degree or doctorate	1208	0.168	0.374
Respondent's marital status:			
1 if married or living together	1208	0.639	0.481
if single - never married	1208	0.254	0.436
1 if divorced, widowed, or separated	1208	0.107	0.309
Household annual income:			
1 if less than or equal €29,999	1208	0.190	0.393
1 if between €30,000 and €59,999	1208	0.292	0.455
1 if above €60,000	1208	0.196	0.397
1 if high socio-economic class (ABC1F50+)	1208	0.495	0.500
Region categories:			
1 if from Dublin region	1208	0.311	0.463
1 if from Leinster region	1208	0.256	0.437
1 if from Munster region	1208	0.258	0.437
1 if from Connaught or Ulster region	1208	0.176	0.381
1 if lives in rural areas (< 1,500 people)	1208	0.335	0.472
Property type:			
1 if flat or apartment	1208	0.157	0.363
1 if Terraced House	1208	0.181	0.385
1 if Detached	1208	0.338	0.473
1 if Semi-detached	1208	0.311	0.463
Home ownership:			

1 if own outright	1208	0.383	0.486
1 if own with mortgage	1208	0.299	0.458
1 if rented	1208	0.315	0.465
Number of bedrooms	1208	3.247	1.205
Main home heating system:			
1 if Oil	1208	0.330	0.471
1 if Gas	1208	0.349	0.477
1 if Electricity	1208	0.155	0.362
1 if solid fuels: wood, coal, peat	1208	0.150	0.357
1 if renewables: solar thermal or heat pumps	1208	0.010	0.099
Satisfaction with existing home heating system:			
1 if dissatisfied	1208	0.196	0.397
1 if neutral	1208	0.339	0.474
1 if satisfied	1208	0.464	0.499
Satisfaction with existing electricity source:			
1 if dissatisfied	1208	0.166	0.372
1 if neutral	1208	0.421	0.494
1 if satisfied	1208	0.414	0.493
1 if aware of at least one RET	1208	0.947	0.224
1 if knows at least one other RET user	1208	0.560	0.497
1 if adopted at least one RET themselves	1208	0.168	0.374

Table 2: Survey respondent characteristics: summary statistics

2.3 Data preparation using factor analysis

The survey contained 25 five-point Likert scales measuring a range of attitudinal characteristics. Rather than analysing each individual scale item as a separate variable, scales that related to similar underlying constructs were grouped to form single-value indices to provide a more useful interpretation in our econometric model. We used factor analysis to find these underlying dimensions and converted the 25 scales into eight separate indices: sustainability, EV fan, hassle factor, social approval, compatibility, satisfaction, risk behaviour, and time preference. The process was as follows.

First, correlation coefficients were estimated for all items. All were under 0.7 verifying that the items were somewhat, but not too highly correlated. Bartlett's test of sphericity was significant (p=0.00), implying that there were sufficient intercorrelations between the items to conduct a factor analysis. Further, the Kaiser-Meyer-Olkin measure of sampling adequacy was 0.88

confirming that the items provided sufficient unique information to the constructs we wanted to identify.

A principal-component factor analysis was then implemented on 924 observations. This method has been extensively used in energy and related domains for data mining and feature extraction (Chen and Lin, 2008; Claudy et al., 2013; Krishnamurthy et al., 2017; Oghenefejiri et al., 2016; Samuelson and Biek, 1991; Sovacool, 2013; Sun et al., 2017). The analysis generated a set of eigenvalues[5] and the proportion of variance that they explained in terms of the variability in the 25 items analysed. The first combination of items explained about 23%, the second factor explained about 9.3%, and so on. To make the factor structure more interpretable, an orthogonal rotation was applied. Eight factors were retained for our dataset, indicating that these factors explained the most variance for the items explored. Our overall scale had an alpha[6] coefficient of 0.86, implying that the factors were valid and internally consistent in measuring the 25 items. Furthermore, each individual trait had an alpha coefficient of at least 0.7 (except *satisfaction*, which had 0.68, thus rounding off to 0.7), confirming that the items that constituted each factor grouping consistently measured the relevant construct. Finally, we determined a theme for each grouping and scaled the values out of 100. Our final indices and their components are listed in Table A.1 in Appendix A.

3. Results

This section describes the factors that influence the decision process for heat pump, EV and solar PV purchase. We present the results from our qualitative and quantitative analyses in turn.

[5] An eigenvalue is the portion of the total variance of a correlation matrix that is explained by a linear combination of factor items. Components with eigenvalues exceeding one are usually retained, after considering the uniqueness of each item, the communalities (that is, 1-uniqueness), and the number of individuals in the analysis. This criterion is reliable when the number of variables is below 30 and the communalities are over 0.7, or the number of individuals is over 250 and the mean communality for all variables is at least 0.6 (UCLA, 2006).

[6] Cronbach's alpha is the internal consistency reliability coefficient (Cronbach, 1951). For exploratory studies, alpha must be at least 0.70 for construct validity (Nunnally, 1978).

3.1 Qualitative insights

First, we summarise our findings from the focus groups and interviews. Opinions expressed are those of the group majority unless stated otherwise.

3.1.1 Heat pump adopters

Installations of heat pump were undertaken as part of broader home improvements. Prior awareness of the technology was low, and specifications were almost always decided by contractors. Knowledge of costs was also low and cost savings were not a key trigger for installing. Overall, the high initial outlay and increased electricity bills experienced post-installation were considered an acceptable trade-off for a more efficient heating system and greater home comfort. Although respondents claimed to be environmentally minded, sustainability did not emerge as a crucial factor in uptake decisions. There was consensus that stronger information and guidance on installation is needed from the national level. Participants also supported the recent Irish building regulations that mandate renewables in all new builds through the installation of either a heat pump instead of a boiler or a combination of gas or oil boiler with solar PVs (Stationery Office, 2017). To facilitate more effective use, participants sought a smarter system that would provide real-time feedback and comparisons on operations and control settings with peers.

3.1.2 Solar PV adopters

Solar PV installations were part of other home renovations such as improved insulation, new boilers, and new windows. Knowledge of technical aspects was low prior to installation and specifications were largely dictated by the contractor. Improvement in building energy rating (BER) and its impact on home value was an attractive proposition for many. Upfront costs were ill understood and not a key barrier although cost savings figured prominently as a key driver associated with a prior impression that PVs would instantly save money. However, none had factored in maintenance costs. Rather than sustainability, costs, feasibility, and peer-to-peer influence were stronger determinants of uptake. There was consensus that a national awareness-building advertising campaign that linked installation with tangible benefits such as improved BER, reduced property tax and increased sell-on home value was needed. Like heat pump adopters, participants valued real-time feedback on usage and savings and found this lacking.

3.1.3 EV adopters

EV purchases were driven mainly by lifetime cost savings and neither high upfront costs nor increased electricity bills post-installation deterred uptake. Engagement with the technology was high and all participants had had home chargers installed with available supports. Only those with no garage or driveway (a minority in this group) had had difficulties in obtaining the required permission from councils and management companies to install a home charger. Participants were primarily long-distance drivers who drove more than the average motorist and were energised by the high performance and acceleration of their vehicles. Initial concerns about battery life, driving range and availability of public charge points were overcome by extensive online research; participants had built up good knowledge of the location of charging infrastructure along their most-frequented routes. None had any concerns about paying for charging at public facilities and considered this necessary. Negative personal experiences such as instances of broken charge points were not compelling enough to deter uptake. Instead, participants logged faulty chargers with the Electricity Supply Board or through online forums to assist fellow EV users. Nonetheless, the general perception was that maintenance was slow and overall, the charging network was technologically behind other countries in terms of geographical spread, numbers, and density. There was consensus that introducing a high-value grant to offset upfront costs and increasing the scale and reliability of public chargers were essential going forward. Although participants claimed to be environmentally minded, there was minimal co-ownership of other RETs. Social influence was low overall.

3.1.4 RET non-adopters

There was spontaneous awareness of EVs and solar PVs but not of heat pumps. Upfront cost was the primary barrier to uptake. Savings were also considered too long term and not worthwhile considering participants' family size (two-person family) and their lifestyle (working 9-5 during the week). The perceived complexity of the information relating to installers and grants was an additional deterrent. Most would use an internet search but preferred all information to be accessible on the one website due to the required time commitment of researching all options. Overall, costs were more important than sustainability when choosing a technology. High energy users were typically more interested in RETs. For solar PVs, the 'hassle' factor was a key barrier especially for terraced houses due to a fear that installation would require additional building changes. For EVs, driving range, charging time and charge point availability were key barriers to uptake; respondents considered them suitable only for city driving. There was consensus that a move towards RETs should be State led.

3.2 Survey outcomes

This section presents insights from our pairwise comparisons between RET adopters and non-adopters and a regression-based analysis of RET uptake.

3.2.1 Characteristics of RET adopters versus non-adopters

Although the focus groups demonstrated that EVs, solar PVs and heat pumps have different owners and attributes, our survey provided insufficient data to analyse each technology individually. Thus, we analysed RET adoption instead. Specifically, out of 1208 survey respondents, our RET adopter sample included 63 EV, 58 solar PV, 99 solar thermal, and 43 heat pump owners of which a few participants owned multiple technologies. We ran a series of non-parametric tests, the Wilcoxon-Mann-Whitney test (Mann and Whitney, 1947), for ordinal data and the Student's t-test (Student, 1908) for continuous data. Table 4 presents detailed group comparisons between RET adopters (*n*=203) and non-adopters (*n*=1005), where adopters were defined as respondents who owned at least one RET.

Attribute	More likely to adopt if:	P value
Socio-demographics:		
Age	Younger	0.000
Gender	Male	0.056
Socio-economic status	Higher	0.004
Education level	Higher	0.000
Employment status	Full-time employed	0.000
Occupation	High managerial/professional	0.000
Marital status	Single-never married	0.011
Children under 17	More	0.000
Children over 17	Fewer	0.000
Social network	Larger, by 6 members on average	0.000
Spatio-technical & building characteristics:		
Region	Dublin	0.001
Property type	Flat/Apartment	0.005
	Not semi-detached	0.007
Property size	Larger (by number of rooms)	0.013
Building era	2006-18	0.000
	Not pre-1976	0.000
Property BER	Higher (A-C)	0.014

Residence period	Lower, by 67 months on average	0.000
Primary heating system	Electric	0.000
	Not solid fuel	0.008
	Renewable (solar thermal, heat pump)	0.000
Bi-monthly heating bill	Higher, by €12.96 on average	0.035
Bi-monthly electricity bill	Higher, by €5.84 on average	0.018
Behaviour:		
BER awareness	Higher	0.000
Perceived household energy usage	Higher	0.013
	Known	0.003
Perceived current heating costs	Cheap	0.000
Perceived future heating costs	Will not increase	0.003
	Will remain similar	0.000
Satisfaction with current home heating system	Higher	0.012
Will change heating system		
Awareness of RET	Yes	0.000
Awareness of other RET owners	Aware of at least one type	0.000
Willingness to try new technology	Higher	0.000
Environmental attitudes	One of the first people to try	0.000
	Believes that fossil fuels do not impact climate change	0.000
	Believes that fuel prices will not rise in the future	0.000 0.000
	Not concerned about the environment	0.003
Happiness levels	Does not buy energy efficient appliances	0.000
	Believes that own decisions impact climate change	0.000
	Very happy	

Table 4: Pairwise comparisons between RET adopters (*n*=203) and non-adopters (*n*=1005) in survey

The pairwise comparisons in Table 4 reveals numerous differences between RET adopters and non-adopters. We highlight a few key insights here. Firstly, the socio-demographic differences may point to the stage of life most current adopters are at: adopters are more likely to be full-time employed and have more children under 17. The focus groups showed that working schedules and family composition impact household energy use which in turn influences RET uptake. Whilst participants employed full time have lower than average energy usage, those with children are likely to record above average use. Secondly, the spatio-technical and building characteristics indicate that newer apartment-style homes are more likely to have the infrastructure in place to install RETs. Notably, adopters are more likely to reside in Dublin, the most populous region and commercial hub of Ireland. Finally, the behavioural traits suggest that non-adopters generally embody more sustainable orientations. However, adopters tend to engage in more proactive behaviours and may have a stronger sense of personal responsibility in responding to climate change.

3.2.2 Binary logistic regression model of RET uptake

Next, we ran a logit model (Walker and Duncan, 1967) to predict uptake. The dependent variable is dummy, which is equal to one if adopter, zero otherwise. We define adopter alternatively as current owner of at least one RET or as a self-reported strong interest to purchase one RET in the future. As explanatory variables, we use a mix of key socio-demographic, spatio-technical, and behavioural characteristics identified from our pairwise comparisons. Table 5 presents our regression results. In Column (1), current adopters were defined as participants who owned at least one RET. In Column (2), potential adopters were defined as participants who demonstrated a strong interest in RETs by self-proclaiming that they were likely to purchase one in the future. Current adopters were also included under Column (2) as the focus groups suggested that those who currently own an RET are very likely to purchase more RETs in the future.

Dependent variable: adopter	Current RET adopter	Potential RET adopter
	(1)	(2)
Socio-demographics:		
25-34 years old	1.094**	0.028
	(0.440)	(0.422)
35-44 years old	-0.992**	-0.950**
	(0.486)	(0.426)
45-54 years old	-0.831	-1.439***
	(0.533)	(0.459)
55+ years old	-0.559	-1.218**
	(0.567)	(0.490)
Single – never married	0.976**	-0.349
	(0.476)	(0.417)
Education (years)	0.086	0.102**
	(0.053)	(0.047)
Spatio-technical & building characteristics:		

Urban location	-0.743**	-0.081
	(0.289)	(0.245)
Number of bedrooms	0.345**	-0.042
	(0.139)	(0.123)
(Below) Average household energy usage	-1.139***	-0.098
	(0.373)	(0.328)
Semi-detached property	-1.201***	-0.302
	(0.420)	(0.363)
Detached property	-1.147**	-0.251
	(0.464)	(0.413)
Rented property	-0.919**	-0.639**
	(0.367)	(0.307)
Building era: 1992-2001	1.131***	-0.236
	(0.410)	(0.309)
Building era: 2006-2008	1.340***	-0.125
	(0.451)	(0.420)
Building era: 2009-2014	2.680***	0.033
	(0.564)	(0.534)
Behaviour:		
Unaware of BER	-1.771***	-0.487*
	(0.257)	(0.252)
Knows other RET users	0.139***	0.334*
	(0.279)	(0.199)
Environmentally sustainable	-0.083***	-0.031
(sustainability index)	(0.014)	(0.011)
Believes EVs are worth considering	0.008	0.075***
(EV fan index)	(0.009)	(0.009)
Social network approves new technology	-0.001	0.016**
(social approval index)	(0.009)	(0.008)
Household infrastructure is RET compatible	0.059***	0.085***
(compatibility index)	(0.011)	(0.009)
Satisfied with home heating, electricity	0.039***	-0.003
(satisfaction index)	(0.009)	(0.007)
Risk taker	-0.004	0.013**
(risk preference index)	(0.007)	(0.006)
Forward looking	-0.009	0.020***
(time preference index)	(0.007)	(0.006)
Intercept	-0.913	-9.080***
	(1.597)	(1.629)
Observations	985	985

Note: standard errors in parentheses. *** indicates p<0.01, ** indicates p<0.05, * indicates p<0.10.

Table 5: Logit regression results for survey data

The regression results were largely in line with our pairwise comparisons. On the one hand, being under 35 and single, having bigger houses dating post 1992, knowing other RET users, and rating highly on the compatibility and satisfaction indices were positive predictors of current uptake. On the other hand, being middle-aged and unaware of own property's BER, living in semi-detached or detached properties, having (below) average household energy use, and ranking highly on sustainability were negative predictors of current uptake. However, educational levels were no longer significant whereas homeownership was a positive predictor. Urban dwellers were also less likely to adopt RETs whereas earlier, location was not significant. Overall, the differences were minor and could be attributed to chance. Since higher educational attainment enhances human capital and generally leads to higher lifetime incomes, we assume that educational levels are a significant positive predictor of adoption in line with other Irish studies (Claudy et al., 2010; Keelan et al., 2009; Läpple et al., 2015; Scott, 1997). The direction of effect is likely to be ambiguous for homeownership and dependent on the technology adopted. For instance, due to market failures such as the classic landlord-tenant problem (Brennan, 1988), there is no incentive for tenants to install PVs or heat pumps and rather difficult for them to use EVs if no home chargers exist. Homeowners are therefore the likely adopters whilst renters could be users of RETs when suitable facilities are provided. Location has been identified as an important parameter in technology adoption in previous studies and we assume a similar stand-point (Graziano and Gillingham, 2015; Michelsen and Madlener, 2012; Nayum et al., 2016; Owen et al., 2013; Plotz et al., 2014; Robinson and Rai, 2015; Staal et al., 2002) . Rather than make any definitive judgments based on location, we consider an understanding of location as an opportunity to design more effective policies and have explored its role in other work on RET adoption (Mukherjee and Ryan, 2020).

Furthermore, different factors influenced current and potential adoption. Features that determined current uptake such as location, property type, building era, property size, household energy usage, satisfaction with home heating, sustainability, and marital status, did not explain potential adoption. Instead, higher educational levels, belief in innovations such as EVs, social approval, and a willingness to take risks and trade current comforts for future gains shaped the potential adopter mindset. Importantly, behavioural factors featured prominently for both current and potential uptake.

4. Discussion and Conclusions

This study uncovered new insights into RET purchase behaviour in an early adopter market. Our focus groups and interviews highlighted the variance of drivers across three RET types – heat pumps, solar PVs, and EVs. Whilst home renovations drove both heat pump and PV installations and owners had low awareness of technical aspects, EVs were actively selected by owners for their cost-saving potential and favourable technical profile. Sustainability was a secondary factor and did not trigger a purchase of any RET on its own. Non-adopters were most likely to adopt RETs based on potential and easily understood cost savings, information on which was deemed generally lacking or inaccessible.

Our pairwise comparisons revealed that current adopters demonstrate distinct characteristics. Adopters tend to be younger and of higher socio-economic status, more likely to live in newer buildings with capacity for bigger families and have higher energy use and significantly larger social networks. Whilst non-adopters generally demonstrate more pro-environment behaviours, adopters are stronger believers that their own decisions influence climate change, indicating greater personal responsibility for their actions.

Our regression estimates suggest that uptake is sensitive to several non-financial factors. The results are mostly intuitive in that we expect bigger households, building compatibility with technologies, BER-awareness, and knowing other RET users to facilitate uptake. However, it also appears that satisfaction with household heating and cooling is a positive rather than negative predictor, and sustainability is a negative rather than positive predictor of current uptake. These observations imply that decisions to invest in RETs have thus far not arisen out of dissatisfaction with household insulation and infrastructure or of environmental concern *per se* but perhaps an interest in innovative technologies, a capacity to pay for them, and a need based on their perceived benefits for a larger family. Potential adopters are also governed by behaviour, notably social approval, which did not affect current uptake. Besides, they are more RET-aware, willing to take risks and forward looking than current adopters.

When enough people make socially desirable choices, the outcomes for society improve. However, human behaviour is complex. Due to irrational decision-making tendencies under uncertainty, people can quickly become part of the problem rather than the solution if not nudged towards favourable outcomes. Overall, it may be relatively more straightforward to address building compatibility issues than influence behaviour. It is crucial then that policymakers understand how behaviour impacts RET adoption and harness opportunities like potential adopters' openness towards innovations to dispel any ignorance or uncertainty that has hindered uptake in the past. We elaborate further on the most salient behavioural features that have a key role in designing policy around encouraging RET uptake.

Behavioural insights

Potential adopters are less likely to be present biased. In other words, they are less likely to give more weight to payoffs closer to the present time when considering trade-offs between two future moments in time (O'Donoghue and Rabin, 1999). Whilst it is anticipated that current adopters, as innovators and early adopters, enjoy some short-term gratification from owning innovative gadgets that come with inherent uncertainties in paybacks and performance, future adopters are more likely to think longer-term and value cost-effectiveness and functional reliability. Thus, measures that make RETs more attractive in the medium-to-long term such as those that ensure reliable payback periods are needed to attract consumers in the current market.

Early adopters of RETs are less likely to display eco-consciousness in this study. This is not completely unexpected as environmentally sustainable behaviours generally require giving up something in the present for an obscure future gain. The time point at which benefits may be received is also often rife with uncertainty. As defined in Kahneman, Knetsch and Thaler (1991), this observed lack of preference for sustainability may be rooted in the endowment effect (that is, wanting to hold onto current acquisitions), loss aversion (that is, disliking forsaking possessions more than liking the acquisition process), and status quo bias (that is, enjoying maintaining the current state of affairs) (Kahneman et al., 1991). Furthermore, reservation prices for commodities tend to differ for people with different endowment levels. Thus, there may be a price mismatch between buyers' willingness to pay for RETs and sellers' willingness to accept payments (Abdullah and Jeanty, 2011). Overall, whilst environmental consciousness may strengthen the intent to purchase RETs (Zeng et al., 2020), it is ineffective as a policy target if capabilities to purchase RETs are not strengthened through boosting financial fluidity first such as via measures that lower upfront costs.

Older generations may be less likely to own RETs due to ambiguity or regret aversion behaviours. Epstein (1999) defines ambiguity aversion as the tendency to prefer known risks over unknown risks when the probabilities associated with those risks are unknown (Epstein, 1999). Loomes and Sugden (1982) define regret aversion as a rational choice under uncertainty entailing the avoidance of distress arising from the errors of commission or omission when making decisions under uncertainty (Loomes, Graham and Sugden, 1982). Gilbert *et al.* (2004) further differentiate between anticipated regret and unanticipated regret and observe a general overestimation of regret for choices that people perceive as having some control over (Gilbert et al., 2004). Overall, in addition to being more technically competent, younger people may be less cautious around their long-term decision-making as they have longer time periods to recover from any setbacks. They may also have a greater tolerance for risk and an openness to experience and feedback that may further reduce their aversion to ambiguity and regret when purchasing technologies with uncertain benefits. Thus, RET purchase opportunities must be enhanced for a more diverse consumer base, perhaps through information campaigns and dependable in-person support services.

Personal recommendations will evidently play an important role in enhancing future RET uptake as current adopters are all extremely vocal about communicating the benefits of technologies, especially EVs, to others. In general, for many future adopters, decision-making regarding innovative technologies will be influenced by communications with trusted members of their social groups. These will be governed by social proof and social norms, which are hugely important in signalling the kinds of behaviour that are socially appropriate (Institute For Government, 2010). Aronson *et al.* (2019) define social proof as other people's influences on one's actions and behaviours (Aronson et al., 2019). Social proof may lead to herd behaviour as receiving information on how other people with similar socio-economic backgrounds behave leads to greater compliance amongst those seeking social approval (Cialdini et al., 1999). Whilst normative influence is expressed as conformity to fit into a social group, informational influence constitutes the search for social cues on how to behave in uncertain situations (Aronson et al., 2019). Allcott (2011) shows that as more and more people adopt an action, the more influential normative feedback becomes (Allcott, 2011).

Overall, the RET consumer base is evolving. Policymakers must recognise the changing role of social processes in adoption and harness its potential in policy design. Both descriptive feedback (such as comparisons of energy consumption with neighbours) and injunctive feedback (such as statements communicating approval or disapproval of (undesirable) behaviour) may help encourage adoption (Cialdini et al., 2006; Farrow et al., 2017; Goldstein et al., 2008).

In summary, wider societal change is the cumulative effect of individual efforts. A major challenge for policymakers is to find innovative ways to influence individual decision-making. When trust in climate science and public institutions is poor, the choices that people have before them must be suitably re-engineered such that they may adopt new behaviours and adapt to new ways of living more easily. In this regard, nudges in the form of financial signals and social engagement may help boost RET adoption. We propose a few strategies below.

Policy implications

Firstly, a preference for environmental sustainability is not a reliable predictor of RET uptake. Therefore, for the scale of climate action needed, national level policies are required to translate preferences and attitudes into pro-environmental behaviour (Claudy et al., 2013; Lane and Potter, 2007). Consumers are most concerned about the initial outlay which is often prohibitive. Accordingly, low cost finance options such as grants and low interest loans that contribute towards the capital costs of energy upgrades would help reduce the financial burden of purchasing RETs substantially. Some of these already exist, such as a grant to purchase EVs when the list price is over €14,000.[7] However, although there was a good level of consideration given to EVs, over half of the survey respondents claimed that their next car budget is under €15,000. Thus, in the case considered, current grant levels are unlikely to trigger a purchase for many. It is crucial then that incentives are designed according to public preferences.

Secondly, many non-adopters prefer not to change their existing systems due to the perceived complexity of energy decisions, various cognitive biases, and a genuine lack of understanding of new technologies and potential cost-benefit trade-offs. Trust in contractors is strong for solar PV and heat pump installations and is likely to continue to be a driver. However, awareness-raising through advertising campaigns will be needed to help defuse inertia and uncertainty amongst those not planning for general home renovations soon. Word-of-mouth recommendation is also key as evident from the large social networks that current adopters enjoy. Government-led training and advisory services and household energy audits would

[7] Current grant levels are available from the Sustainable Energy Authority of Ireland (SEAI, 2020b).

bridge the current knowledge and skills gap further by helping households understand technology better and thereby take actions for better home energy management.

Finally, policies must be updated to be more inclusive of diverse user types. Current EV owners in this case study were almost all wealthy urban homeowners with private garages, driveways, or parking spaces to charge their vehicles at home. There are opportunities, therefore, to expand uptake in rural areas, where people have the capacity for home charging and have otherwise little public transport alternatives to reduce their carbon footprint. However, as the current incidence of public chargers has been unsuccessful in removing range anxiety amongst non-adopters, a more extensive and reliable charging network would need to be immediately prioritised to attract customers living in rented accommodation or apartment buildings without charging facilities.

Further policy measures related to cost savings during use such as lower motor tax, free parking and free public charging would help complement subvention programmes. The survey revealed a preference for used cars for those considering a vehicle change and budgets under €15,000, which indicate that a bigger used car market for EVs could play a positive role in boosting uptake. For solar PVs, fair payments for electricity generated (that is, feed-in-tariffs) may act as a supplementary incentive to help counteract the lengthy payback periods, especially for consumers who are unable to use all the energy they generate during the day. Free BER assessments with each heat pump installation may attract new heat pump customers especially when accompanied by clear messaging on the benefits of acquiring BER certification. For both solar PVs and heat pumps, users would benefit from home energy consumption feedback such as via an in-home display (Bonino et al., 2012).

Overall, as technologies continue to improve and prices plummet, increased uptake will require a societal transformation through public engagement, a suitable regulatory framework and empowerment of individual consumers in their long-term energy decisions. In the context of a national move towards more sustainable forms of energy and energy use, it is crucial that policy measures appeal to the cultural factors that drive people's behaviours. This can be achieved through widespread dissemination of accurate information on use and necessary behavioural changes, the creation of positive social feedback that often triggers a multiplier effect, and making it generally easier for potential consumers to switch to new technologies through grants and other incentives such as the opportunity to trial technologies before requiring a commitment to purchase. Implementing smart policies today will ensure a more efficient energy transition, making it more likely that we meet our environmental targets, sooner.

Acknowledgements

The authors thank ESB Networks for funding the data collection and Amárach Research for assisting in data collection and preliminary reporting of qualitative findings. Informed consent was obtained from all participants involved in this research and the full study received approval from the UCD Office of Research Ethics before data collection commenced. Sanghamitra C. Mukherjee is grateful to the UCD School of Economics and the Irish Research Council for research scholarships. Tensay Hadush Meles received funding from the Irish Research Council. Lisa Ryan has been supported by Science Foundation Ireland (SFI) under the SFI Strategic Partnership Programme [grant number SFI/15/SPP/E3125] and has received funding from the Irish government Department of Communications, Climate Action and Environment, the Irish Research Council, the Geological Survey of Ireland and the Sustainable Energy Authority of Ireland [grant number RfPS/2016/34]. There are no known conflicts of interest.

Data Statement

Unfortunately, we do not have permission to make the primary data associated with this research available due to data confidentiality reasons.

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