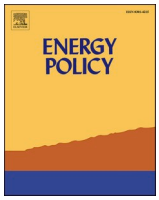
Energy Policy 181 (2023) 113693

Contents lists available at ScienceDirect

Energy Policy

journal homepage: www.elsevier.com/locate/enpol



Understanding domestic consumer attitude and behaviour towards energy: A study on the Island of Ireland

Alastair Brown [a], Harrison Hampton [a], Aoife Foley [a,b,c], Dylan Furszyfer Del Rio [a,d,*], Christopher Lowans [a], Brian Caulfield [c]

[a] School of Mechanical and Aerospace Engineering, Ashby Building, Queen's University Belfast, United Kingdom
[b] School of Engineering, The University of Manchester, Oxford Rd, Manchester, M13 9PL, United Kingdom
[c] Department of Civil, Structural and Environmental Engineering, Trinity College, Dublin, Ireland
[d] Science Policy Research Unit (SPRU), University of Sussex Business School, United Kingdom

ARTICLE INFO

Keywords:
Energy survey
Domestic consumer
Ireland
Northern Ireland
Net-zero transition

ABSTRACT

Attitudes towards renewable technologies and knowledge about energy consumption influences the adoption of sustainable energy systems across power, heat and transport. Research suggests that behavioural change strategies could accelerate the transition towards net-zero by reducing household energy consumption, increasing the uptake of energy efficient technologies and optimising consumption patterns. In tandem, emerging markets and business models facilitated by energy decentralisation and digitalisation give consumers more control over their home energy management and adopt more energy efficient behaviours. This empirical study seeks to determine the level of awareness of domestic consumers on the island of Ireland, which makes for an interesting case study due to the existence of a single electricity market with a dichotomic regulatory regime. This survey is critical to engineers, industry and other stakeholders in understanding the implications of climate policy aspirations and targets as society transitions towards carbon neutrality. A questionnaire was issued to a sample of 1,373 respondents in March 2022, facilitated by a third-party survey provider. The questionnaire had 40 questions composed of multiple-choice and single-answer format; questions covered participants' sociodemographic attributes, their willingness to adopt new technologies and services and their eco-credentials. The results identify the strengths, weaknesses and opportunities for householders to adopt more efficient household energy behaviours and attitudes towards smart energy technology and their carbon footprint. This study explores the emerging, yet significant role of domestic consumers in an equitable transition to a sustainable future.

1. Introduction

The net-zero transition is deemed a necessary and urgent process to limit the adverse affects of climate change. Achieving this, in part, requires reducing global carbon emissions from energy supply and demand by deploying more energy efficient technologies and increasing the share of renewable generation in the energy system. International commitments such as the Paris Agreement and national plans such as the Republic of Ireland's (ROI) Climate Action Plan (Irish Government, 2021) and the United Kingdom's (UK) Net Zero Strategy (UK Government, 2021) will be easier to achieve if policy interventions would consider psychological, social, cultural, and organisational factors that influence energy choices, along with elements of an infrastructural, technical, environmental and economic nature (Stern and Dietz, 2020), (Gunfaus and Waisman, 2021), (Stern et al., 2016). By integrating these factors in energy policies, it would be more likely to add an element of holism (i.e., observing the energy system as an integrated assembly rather than individual parts) to modifying and integrating renewable energy systems, achieving emissions reduction targets and embracing a just transition towards carbon neutrality (Hansen et al., 2019), (Süsser et al., 2022).

Our study centres on domestic energy consumption, where householders' behaviours and adopting energy efficient technologies are key in mitigating emissions emerging from this sector. The importance of investigating this subject becomes apparent when in 2020, households represented 27.4% of the final energy consumption in the European Union (EU) (Eurostat, 2020) and progress has been made with

* Corresponding author. Mechanical & Aerospace Engineering, Queen's University Belfast, Belfast BT9 5AG, United Kingdom.
E-mail addresses: abrown76@qub.ac.uk (A. Brown), hhampton01@qub.ac.uk (H. Hampton), aoife.foley@manchester.ac.uk, a.foley@qub.ac.uk (A. Foley), D.Furszyfer@qub.ac.uk, D.D.Furszyfer-Del-Rio@sussex.ac.uk (D. Furszyfer Del Rio), clowans01@qub.ac.uk (C. Lowans), Brian.Caulfield@tcd.ie (B. Caulfield).

https://doi.org/10.1016/j.enpol.2023.113693
Received 20 March 2023; Received in revised form 19 May 2023; Accepted 25 June 2023
Available online 15 July 2023

Nomenclature

Abbreviation	*Description*
EU	European Union
GDP	Gross Domestic Product
HDI	Human Development Index
I-SEM	Integrated Single Electricity Market
NI	Northern Ireland
ROI	Republic of Ireland
UK	United Kingdom

improving how this energy is consumed. For example, a case study in the EU showed that each household could achieve annual savings of up to 1300 kWh by combining more energy efficient technologies and adopting efficient household energy behaviours (Almeida et al., 2011). In the UK, the domestic sector alone emitted 68.1 $MtCO_2$, representing more than 19% of all UK CO_2 emissions (Uk Government Dep. for BEIS, 2022). To moderate emissions, the UK Committee for Climate Change highlights the role of behaviour change and estimates that 62% of the actions required to achieve the national emissions targets will involve some element of societal or behavioural change (Moon, 2020).

Indeed, a broader understanding of the occupants' behaviours and preferences is paramount when studying domestic energy consumption since individuals' actions highly influence national emissions targets and could ease pressure on the power grid, thus facilitating the integration of renewable sources in the energy system ("The Potential of Behavioural Interventions, 2021). In this context, it is critical to understand what motivates domestic consumers to conserve energy, reduce their carbon footprint, adopt low-carbon technologies and their acceptability of broader carbon emission mitigation measures and energy system changes (Mi and Jiang, 2023), (Perlaviciute et al., 2021).

The aim of this study is threefold and seeks to understand (1) domestic consumer climate change perceptions and energy concerns, (2) significant factors related to domestic consumer energy decision making and (3) domestic consumer attitude towards energy technologies. We explore these themes through an online questionnaire distributed among 1,373 respondents residing on the island of Ireland. The questionnaire had 40 questions composed of multiple choice and single answer format. Our study considered a demographic profile following these parameters: country of residence, province, location, residence type, age, gender, employment status and annual income bracket. The respondents also answer questions regarding their household's efficiency, eco-credentials, and willingness to adapt to new technologies and services.

The results of this study relate specifically to the case study region and the representative sample, with the objective of identifying the strengths, weaknesses, opportunities and threats for householders to adopt more energy efficient behaviours, better understand their energy needs and the concept of their carbon footprint and attitudes and perceptions towards smart energy technology. The study is situated around harmonising the three core dimensions of the 'Energy Trilemma' concept (i.e., 1. energy security, 2. energy equity and 3. environmental sustainability) (Marti and Puertas, 2022); this concept is integrated throughout the narrative of our study. We consider this research to be crucial to support the delivery of a robust all-island energy system that meets sustainable development goals for the Republic of Ireland and Northern Ireland (NI) regions. Internationally, this research supports engineers, industry, and other stakeholders in understanding the implications of policy aspirations and targets as we transition to net-zero by 2050. In this context, this study could be employed to complement future or ongoing research to understand domestic consumers' attitudes and behaviours towards energy in similar regions around the world.

This paper is divided into eight sections. Section 2 presents a background to the island of Ireland. Section 3 presents a literature review contextualising energy behaviours. Section 4 describes the research design and provides the demographic attributes of the participants, the statistical analysis employed in this research, and the study limitations. Section 5 gives an overview of the results and analysis under the following sub-sections: "energy supply and expenditure", "climate change and low carbon technology", and "energy conservation behaviours." Section 6 provides a narrative surrounding the results of this study, and finally, Section7 concludes with policy recommendations.

1.1. Motivation and contributions of our study

The motivation for this study is based on the urgency to address climate change through the optimisation of energy systems, globally. This work focuses on a case study region, the island of Ireland, however it is our aspiration that this study gives valuable insights and similar studies can be replicated for other regions. This study contributes towards state-of-the-art research relating to domestic energy consumers and their emerging, yet significant role in an accelerated and equitable net-zero transition.

The primary contributions of this study include:

(1) A representative sample of domestic consumer climate change perceptions and energy concerns, especially with the ongoing energy crisis and rising cost of living, are quantitified and analysed.
(2) Cross-links are established between demographics and energy behaviours. Furthermore, significant factors related to domestic consumer energy decision making are discussed.
(3) Domestic consumer attitudes, for the case study region, towards renewable energy technologies and emerging flexible energy pricing tariffs are outlined.

2. Background

Ambitious climate change targets have been set globally and the island of Ireland is complementing global efforts by establishing significant policy frameworks to help ensure such targets are achieved (e.g., the Republic of Ireland's Climate Action and Low Carbon Development Bill 2021 (Government of Ireland, 2021a) and Northern Ireland's Energy Strategy: Action Plan published in 2022 (Northern Ireland Executive, 2022)). These crucial roadmaps and policy frameworks focus on effective and efficient directed actions on fossil fuel reduction, optimising energy demand and developing sustainable electricity generation. However, with such ambitious action plans to achieve net-zero within multi-year time constraints, perhaps more emphasis should be allocated to the role of domestic energy consumers and their energy conservation and carbon emission mitigation behaviour. It is important to consider that climate change perceptions play an extensive role in how strongly consumers support decarbonisation policies and whether mitigation actions set out in net-zero roadmaps are actually realised (Valkengoed

Table 1
– Population, GDP and HDI information for island of Ireland. Source, authors, compiled from: ("Ireland Population Growth Rate, 1950, 1950, 1950), (The World Bank and Ireland, 2022), (United Nations Development Programme, 2022), (NISRA) (Office for National Statistics, 1998),

Region	Population	GDP	HDI
Republic of Ireland	4,985,673 (2020)	€426 billion (2020)	8 out of 191 countries (2022)
Northern Ireland	1,895,510 (2020)	£48 billion (2020) contributing around 2.25% towards the UK's GDP	NI is part of the UK, and when considering the UK collectively, the region is ranked 18 out of 191 countries in the HDI (2022).

et al., 2021), (Ruiz et al., 2020). To provide broader information for the purposes of this study, Table 1 provides population, GDP (gross domestic product) and HDI (Human Development Index) information for the island of Ireland.

Statistics relating to the domestic energy sector on the island of Ireland are presented in Table 2. Note that the energy prices provided in Table 2 are captured in a moment in time and are currently, as of December 2022, experiencing volatility due to several cascading factors originating from events with significant international impact such as the Ukraine – Russia conflict and the Coronavirus pandemic.

The standard of the domestic building stock on the island of Ireland is an important consideration as the physical characteristics of homes are linked directly with energy efficiency (Uidhir et al., 2020). To improve energy efficiency of existing homes and new builds, enhancing the thermal envelope is essential (U.S. Department of Energy and NREL, 2000). On the island of Ireland, heating methods differ depending on the housing stock location (i.e., if the dwelling is in an urban area or rural area). The predominant heating fuel source utilised in homes on the island of Ireland is oil, with 38% of households in the ROI (2019) and 68% of households in NI (2016) consuming this fuel source (Rural Energy Ireland, 2019), (National Statistics and Housing Executive, 2016). Furthermore, rural homes in the ROI are typically larger and disconnected from natural gas networks and thus consume higher quantities of oil (65% 2019), as well as solid fuels such as coal and peat, than that of urban housing stock (Rural Energy Ireland, 2019). Most households consume energy in the form of electricity, gas and heating fuel. Over the past decade, renewable generation has been increasingly produced electricity on the island of Ireland, with the ROI having an ambitious targets to reach 80% renewable electricity by 2030 supported by delivering 5 GW of offshore wind (Soni, 2022). Similarly, in NI, 40% of electricity is currently derived from clean sources and the region is aiming for 70% by 2030 (SONI, 2021). Table 3 displays the average fuel mix for both regions over the year 2021 ("System and Renewable Data Summary, 2021).

The energy system on the island of Ireland is unique due to the cross-jurisdiction wholesale electricity market established between ROI and NI. This market arrangement is called the I-SEM (Integrated Single Electricity Market), which went live in October 2018 and permits market coupling with electricity markets in Great Britain and Europe via interconnectors (SEM Committee, 2022a). The I-SEM comprises two spot markets (day-ahead and intra-day market), a balancing market, two financial instrument markets (forwards market and financial transmission right auction) and a capacity market, which all operate independently from each other, with each having their respective timelines ("Quick Guide to the Integrated, 2016). There are also significant retail markets for domestic home heating across the island of Ireland, where the price is related to the wholesale price of oil but also varies extensively by region (The Consumer Council, 2022b), (OilPrices.ie, 2022). Energy markets are adapting to accommodate an increased focus on flexibility due to new technologies (e.g., the transition toward intermittent renewables with non-synchronous attributes and distributed energy systems), complex grid management and stakeholder roles in the market. Therefore, domestic consumers, distribution system operators and domestic energy retail suppliers are likely to have a significant role to play in the retail energy market (i.e., prosumer activity, increased transparency of both financial and power information, improved control of supply and behind-the-meter generation) (Rafferty ESB Emerging Technologies and R&D, 2019). The retail electricity and natural gas market on the island of Ireland is a competitive environment comprising many incumbent and emerging companies, as Table 4 illustrates.

Table 2
Domestic energy sector overview on the island of Ireland. Source, authors, compiled from: (Sustainable Energy Authority of Ireland, 2022a), (Department for the Economy, 2022), (Commission for Regulation of Utilities, 2020a), (Power to switch, 2022), (Electric Ireland, 2022), (Energy Saving Trust, 2022a), (The Consumer Council, 2022a) (Oil Prices, 2022), (ISEA Irish Solar Energy Association, 2021), (Cowan and Liu, 2021), (Sustainable Energy Authority Of Ireland, 2020), (Uidhir et al., 2020), (U.S. Department of Energy and NREL, 2000).

Parameter	Republic of Ireland	Northern Ireland
Domestic final energy consumption	• 33494 GWh (2019)	• 15,928 GWh (2019)
Typical annual energy consumption per household	• 4,200 kWh electricity (2020) • 11,000kWh natural gas (2020)	• 3,200 kWh electricity (2020) • 13,500kWh natural gas (2020)
Typical price per unit of energy	• €0.39 per kWh for electricity (2022) • €0.13 for natural gas (2022) • €656 per 500 L of home heating oil (2022)	• £0.34 for electricity (2022) • £0.10 for natural gas (2022) • £526 per 500 L of home heating oil (2022)
Electric vehicle ownership	Estimated at 1.5% EV ownership (2019)	0.4% of vehicles registered as electric or ultra-low emission (2021)

Table 3
Average fuel mix over 2021 for the island of Ireland. Source, authors.

Fuel	Fuel mix share
Natural gas	46.9%
Renewables	35.3%
Coal	9.5%
Oil	3.6%
Net imports	3.3%
Peat	0.8%

The ROI has established recent legislation, namely, Climate Action and Low Carbon Development (Amendment) Act 2021 (Houses of the Oireachtas, 2021) and has committed to reducing greenhouse emissions by 50% by 2030 against 2018 levels and reaching net-zero by 2050 according to the Climate Action Plan 2021 (Government of Ireland Department of the Taoiseach, 2022). This plan focuses on a range of elements and sectors such as citizen engagement, a just transition, investment, electricity, enterprise, buildings, transport, agriculture, land use, adopting a circular economy, the public sector, governance, sustainable development and international climate action and adaptation (Government of Ireland, 2021b).

Meanwhile, NI, has established recent legislation, namely the Climate Change Act (Northern Ireland) 2022 ("Climate Change Act, 2022) and NI's Department for the Economy has recently released the Energy Strategy for NI: Action Plan 2022. This document sets out plans based on improving energy efficiency (i.e., deliver energy savings at 25% from buildings and industry by 2030), increasing renewables (i.e., ensuring renewables meet 70% of electricity consumption by 2030) and developing the green economy (i.e., reach a turnover in excess of £2 billion by 2030) (Northern Ireland Executive, 2022), (Energy Saving Trust, 2022b). The energy system in ROI, being part of the EU, is largely influenced by European Commission directives such as Renewable Energy Directive 2018/2001/EU and Energy Efficiency Directive 2018/2002/EU (European Commission, 2022). Whereas, as part of the Brexit[1] negotiations in the UK, NI has a trading arrangement in place called the Northern Ireland Protocol which "provides the basis for the continued operation of the Single Electricity Market and trade of wholesale electricity across the island of Ireland" (The Northern Ireland Protocol, 2020).

[1] Brexit was the withdrawal of the UK from the EU which occurred in January 2020.

Table 4
- Major energy retailers in the Republic of Ireland and Northern Ireland by domestic market share in 2020. Source, authors, compiled from (CRU, 2021), (UREGNI, 2021).

Region	Republic of Ireland		Northern Ireland	
Fuel Type	Electricity	Natural Gas	Electricity	Natural Gas
Company and market share by number of connections	Electric Ireland, 50.6%	Bord Gáis Energy, 42.8%	Power NI, 54.9%	SSE Airtricity, 74.6% (domestic credit market share) 57.7% (domestic prepayment market share)
	Bord Gáis Energy, 15.9%	Electric Ireland 21.0%	SSE Airtricity, 19.6%	Firmus, 25.4% (domestic credit market share) 42.4% (domestic prepayment market share)
	SSE Airtricity, 10.7%	SSE Airtricity 11.0%	Electric Ireland, 11.1%	
	Energia, 8.6%	Energia, 9.8%	Budget Energy, 10.7%	
	PrePayPower, 7.6%	PrePayPower, 8.3%	Click Energy, 3.6%	
	Panda Power, 2.5%	Flogas, 3.9%		
	Pinergy, 1.3%	Panda Power, 1.77%		

3. Literature review: survey studies and context to energy behaviours

In this section, a literature review is compiled focusing on energy choice and decision making, domestic energy technologies, survey studies addressing domestic energy use and concludes with a narrative contextualising energy behaviours. This section provides context to our results, discussion and conclusions.

3.1. Energy choice and decision making

Energy choice is a key component of liberalised retail electricity markets, permitting domestic and commercial consumers to browse and select the most suitable pricing structure. Online price comparison tools are a popular way to compare a spectrum of tariffs. In addition to choice of a particular supplier and associated tariff, there is broad flexibility in terms of payment method depending on individual consumer circumstances and preferences, for example, direct-debit, pay as you go and pay on receipt of bill. The unit price of electricity and natural gas for consumers residing on the island of Ireland is calculated based on several constituent costs, these are supply, network, wholesale energy costs and value added tax. Additionally, a levy called the Public Service Obligation is included to support schemes which promote and help implement sustainable electricity generation (Commission for Regulation of Utilities, 2020b), (Utility Regulator, 2022). Energy choice is expanding for domestic consumers with multi-rate time-of-use tariffs emerging, which offer a range of intraday rates and aim to provide enhanced demand flexibility (Belton and Lunn, 2020), (Yunusov and Torriti, 2021). Innovative time-of-use (Bairrão et al., 2022) and vehicle-to-grid export tariffs (Dixon et al., 2022) are of particular importance with the increasing penetration of electric vehicles on the island of Ireland.

Energy decision making is an extensive topic and relates not only to the choice of energy supplier and pricing arrangement but the efficiency of appliances, the level of consumption and with the adoption of multi-rate tariffs and the timing of consumption. Even the energy decision-making process itself is nuanced as energy consumers tend to deviate from traditional economic principles, and the application of behavioural psychology is appropriate for understanding energy decision-making, especially for analysing the effects of phenomena such as consumer inertia (Frederiks et al., 2015a).

3.2. Domestic energy technologies

As the island of Ireland strives towards carbon neutral energy systems, the development and adoption of new domestic energy technologies will increasingly play a pivotal role. The widespread adoption of smart home technologies and energy efficient appliances provides an opportunity for efficient energy management, potential financial savings, improved device control and enhanced consumer convenience (Furszyfer Del Rio et al., 2020).

The significant domestic energy technologies are addressed in this study under two primary themes: 1. domestic heating and 2. domestic energy management. For domestic heating, heat pumps (Gong et al., 2023), solar thermal panels ("Generating renewable electricity, 2023) and energy efficient boilers (Kerr and Winskel, 2022) are observed as key systems for decarbonisation and for domestic energy management, the following tend to be instrumental in harnessing domestic energy demand and home electricity generation: solar panels and batteries, smart home management devices, smart utility meters, electric vehicles and energy efficient appliances (Ayub et al., 2022). One of the most significant and far-reaching energy technologies becoming available for many domestic consumers is the smart energy meter (Sovacool et al., 2021a).

As domestic energy management systems are adopted across the island of Ireland, it is crucial to recognise that there is both a technological and psychological element to consider, after all consumers are going to be encouraged to adapt from long-term and well-established behavioural patterns (e.g., reallocating energy consumption to another period of the day to avail of a demand response incentive). Energy management systems with integrated near real-time feedback mechanisms are an essential software component which complements smart energy meters. Feedback mechanisms monitor individual consumer usage, help improve domestic energy efficiency and alleviate grid congestion (Trinh et al., 2021), (Mukai et al., 2022), (Stawska et al., 2021).

3.3. Survey studies addressing domestic energy use

In this sub-section, a brief discussion of related state-of-the-art works

was compiled. This paper builds upon and supports existing published research focusing on the domestic energy sector. Several energy system studies feature a survey as the fundamental component of the study and relate to the case study region, the island of Ireland.

In Lowans et al. (2023), energy and transport poverty were examined across NI (n = 431) and the ROI (n = 1133) and this study incorporates an informative section concerning attitudes and behaviours related to domestic energy use. Smart home technology is likely a key enabler of enhancing the role of domestic energy consumers in the broader pathway to net zero, and Sovacool et al. (2021b), focus on the user acceptance of smart home technology via three focus groups (n = 18) and an online survey (n = 1032). Gauging public opinion towards specific energy technologies is crucial prior to mass implementation and Cronin et al. (2021), capture this sentiment by analysing the public perception of offshore wind farms in Ireland using an online survey (n = 1154).

The proliferation of interconnected digital technologies is providing new opportunities to efficiently manage energy and Furszyfer Del Rio et al. (Furszyfer Del Rio et al., 2021), explore perceptions of such technologies with a focus on gender related biases and the implications this has on sustainability. A community engagement approach to energy systems modelling is presented in McGookin et al. (2022), where several community meetings were conducted (n = 400 approx.) to support the alignment of rural development with climate action policies. Heating of homes is an essential aspect of the domestic consumer sector and both Eakins et al. (2023), and Coggins et al. (Coggins et al., 1092), explore residential heating, focusing on solid fuel usage (n = 1823) and retrofitted dwellings (n = 14 dwellings), respectively. Further to studies which contain a survey or questionnaire element, there is a comprehensive range of works related to the domestic energy sector on the island of Ireland. These studies include topics such as renewable heating technologies (Kennedy and Basu, 2013), (Meles and Ryan, 2022), (Gaur et al., 2022), energy consumption metrics (Brophy et al., 2021), (Guo et al., 2022) and building energy efficiency (Norouzi et al., 2022), (Pillai et al., 2021).

3.4. Contextualising energy behaviours

Contextualising energy behaviours is a complicated endeavour, as they are multifaceted and often hold multiple dimensions, however, Lopes et al., p. 85, (Lopes et al., 2015), have made a concerted effort to categorise energy behaviours into the following behavioural sub-categories: investment, maintenance and usage. These are further described in Table 5.

Table 5
Energy behaviour and sub-categories of Investment, Maintenance and Usage (Li et al., 2019a).

Subcategory	Definition
Energy	"*observed acts that lead to energy consumption or conservation and include investment, maintenance, and usage behaviours as well as the management and provision of energy resources.*"
Investment	"*those involved in the purchase of new technologies, including its energy attributes and its relative importance in the choice process. They are also commonly designated as efficiency behaviours.*"
Maintenance	"*behaviours involved in the repair, maintenance and improvement of energy consuming equipment including the building.*"
Usage	"*behaviours refer to the day-to-day usage of buildings and equipment, and may be characterised by frequency, duration, and intensity*"

3.4.1. Influencial factors of proactive energy behaviour and associated feedback mechanisms

Garcia et al. propose a multivariate statistical approach using survey data to assess the impacts of five factors: energy price, household income, education level, age of head of household and dwelling energy performance on energy-saving behaviours (Belaïd and Garcia, 2016). The results show that energy price significantly impacts energy-saving behaviours and income; there is no effect of changing the energy consuming habits of households. The study also notes that have a negative influence on energy-saving behaviours and how attitudes towards investment behaviour are encouraged by educational attainment factors.

Feedback mechanisms show consumers the evolution of their energy consumption patterns throughout the day and across seasons. They aim to raise awareness about how daily use of appliances, heating and air conditioning affects energy expenses. Feedback can be provided in real time, through in-home displays, mobile applications or web portals fed with data from smart metering systems (Nilsson et al., 2018). Furthermore, policy interventions and demand response programmes can simultaneously exploit behavioural levers. For example, the International Energy Agency acknowledges that energy-saving competitions (i.e., introducing the concept of gamification into the domestic energy sector (Bassanelli et al., 2022)) "can leverage social comparisons among consumers of the same energy utility and engage participants through real-time feedback as well as set milestones and targets that trigger rewards" ("The Potential of Behavioural Interventions, 2022). However, for any policy intervention to be successful, simplification and transparency is key to making communications such as energy bills and monthly reports clear and user friendly.

Accordingly, increasing energy efficiency by adjusting energy behaviours to more efficient patterns require targeting important precursors of behaviour, and removing significant barriers to change. In (Werff et al., 2015), Steg et al. discuss three key influencing factors behind sustainable energy behaviour: knowledge and awareness, motivational factors, and contextual factors. In general, people are well aware of the problems related to household energy use and are concerned about these problems. Yet, knowledge of the causes and consequences of climate change and the impact of human behaviour on climate change is not always accurate. For example, there is still confusion about the processes that cause global warming.

A study by Li et al. concludes that "environmental concern and environmental knowledge have a significant impact on the willingness to purchase and adopt low carbon technologies more so even than subsidy policies" (Li et al., 2019a). They also highlight how uptake is closely related to the residents' education level and social popularity. This is reinforced in a household survey conducted by Brounen et al. who noted a low awareness among respondents with just 56% displaying knowledge of their monthly energy bills, and 40% who did not evaluate investment decisions in energy efficient equipment (Brounen et al., 2013). They also document that demographics and consumer attitudes towards energy conservation directly affect behaviour regarding home heating and cooling. In (Frederiks et al., 2015b), Frederiks et al. highlight how in terms of relaying information to consumers, "complexity and sensory overload should be avoided by framing messages in a clear, concise, and comprehensible format". As opposed to delivering information-intensive campaigns, behavioural strategies would be better communicated through simple messages that the average consumer can easily understand.

3.4.2. Perceptions of energy use and motivaton to adopt habits which support energy conservation

Previous research (Schuitema and Steg, 2005), (Attari et al., 2010) has highlighted how people's perceptions of energy use through their behaviours are not always accurate. This implies that they may not accurately judge which behaviour changes effectively reduce energy consumption and related CO_2 emissions. People tend to rely on a simple heuristic when assessing the energy use of household appliances, notably the size of appliances. The larger the appliance, the more energy it is believed to use, which is not always true. This may lead to underestimating the energy use of small appliances, such as kettles, and overestimating the energy use of large appliances, such as washing machines. Steg et al. note that people tend to underestimate the energy needed to heat water and misjudge the energy savings attainable by minor energy curtailment behaviours.

In the case of motivational factors, these are simply defined as the enthusiasm for doing something. There are two types of personal motivation discussed in (Bishoge et al., 2021). Extrinsic motivation occurs when a person is motivated to perform a behaviour or engage in an activity to earn a reward or avoid punishment. In this case, the person engages not because they find satisfaction but to get something in return or avoid something unpleasant. Secondly, intrinsic motivation exists when a person involves themself in behaviour because it is personally rewarding; essentially, performing for their own sake rather than the desire for some external reward. In (Steg and Vlek, 2009), Steg et al. explain how "people are more likely to engage in low-carbon behaviours when they associate these behaviours with higher benefits and lower costs and risks". High upfront costs of low-carbon technology may reduce the likelihood of adoption therefore, subsidies and cost reductions are required to increase their financial attractiveness (Kastner and Stern, 2015).

However, the dramatic increase in fossil fuel prices sparked by conflict in Ukraine could lead to a paradigm shift whereby consumers ascribe high collective costs and low collective benefits to fossil fuels, including oil, coal, and gas. Aside from personal costs and benefits, people are also motivated to achieve benefits for the environment and other people. Acting in favour of the environment and others can feel meaningful and evoke positive affect, which motivates action based on hedonic reasons (Steg et al., 2014). Interestingly, emphasising the benefits for health and comfort and the environment may motivate low-carbon behaviour more than emphasising financial benefits (Schwartz et al., 2015). Fossil fuels are typically evaluated as polluting, contributing to climate change, finite, and causing global conflicts, whilst nuclear energy bears additional associations with radioactive waste disposal and nuclear accidents. Renewable energy sources, in contrast, are typically evaluated as safe and clean.

Some sustainable energy behaviours have clear individual benefits. For example, some people may enjoy cycling more than driving a car, saving energy at home will save money, and driving an electric vehicle may enhance people's status. However, sustainable energy behaviours can sometimes be costly (Faiers et al., 2007), effortful (Li et al., 2019b) and could require the adaption of domestic consumer lifestyles (Bourgeois et al., 2017). For example, insulating a home or installing roof-top solar panels can often include a large upfront cost and inconvenience of installation. Meanwhile, switching off appliances may be more effortful than leaving them on standby, and using appliances only when sufficient renewable energy sources are available or to alleviate grid conjestion, can limit domestic consumer freedom of choice and could demand a lifestyle change.

Sociotechnical factors together with psychological and socio-demographic variables, influence individuals' or societal behaviours towards energy saving. For example, the policies of increasing carbon dioxide tax and other energy-related taxes in Sweden have encouraged households to change their energy-consuming behaviour more efficiently and apply different energy models (Martinsson et al., 2011). Furthermore, in (Marien and Hooghe, 2011) it is highlighted how low trust in political institutions results in less public willingness to defer to decisions taken by those institutions. The willingness to change energy behaviour in line with policy intentions affecting households' choice of energy behaviour might increase among households with higher levels of trust in the government and its institutions. A further study (Konisky et al., 2008), found that respondents with higher levels of confidence in government are more likely to support government action to address issues such as climate change and the protection of the environment. Such findings suggest that the degree of compliance with policy intentions among targeted groups will be associated with overall citizen trust in politicians and political institutions.

4. Methods

This section discusses the survey development, statistical analysis of the results and the research limitations.

4.1. Research design

The overall scope of this study is to investigate people's attitudes towards the energy transition and particularly to understand how individual behavioural change at home can be effectively promoted in

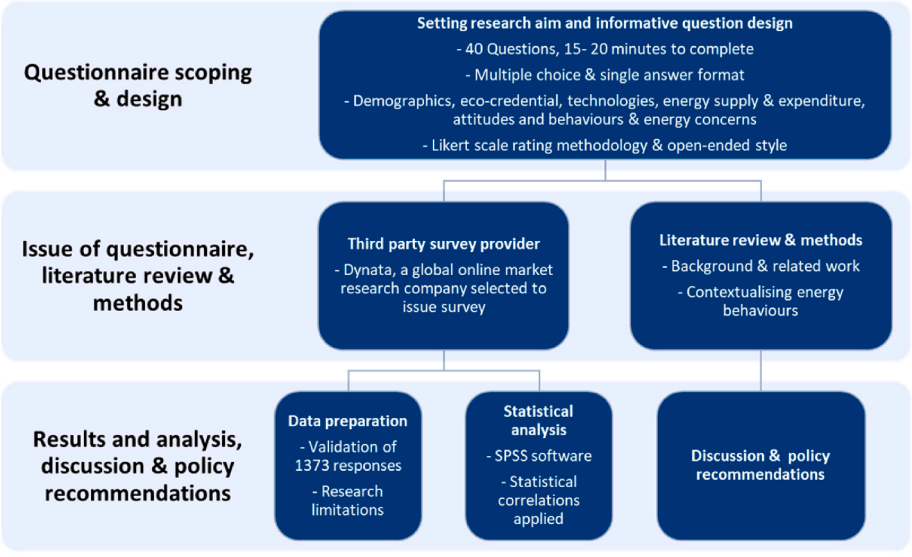


Fig. 1. Research framework from initial questionnaire design to policy recommendations, source, authors.

supporting this process. To do this, we rolled out a nationally representative survey on the island of Ireland; the questionnaire was designed for a non-technical audience and entailed 40 questions developed by the research team. The total number of people who participated in the survey was 1380 however after screening 7 respondents were removed and data was carried forward for 1373 respondents. The questionnaire was designed to be completed within 15–20 min and was divided into three sections. The first section assessed the demographics of the respondents. The second section assessed respondents' opinions on climate change and knowledge of renewable technologies. The third section asked questions relating to energy supply, expenditure, attitudes and behaviours regarding domestic energy use and energy concerns. Various question types were chosen such as multi-choice, Likert scale and open-ended style. Fig. 1 explains the framework for the survey design, analysis and conclusions.

It was decided to outsource the delivery of the survey to Dynata, a global online market research company as they have an existing database of respondents from a wide range of demographics giving a more representative sample. Dynata scripted the survey in collaboration with the research team in order to minimise anomalies. Respondents under 18 and those who do not reside on the island of Ireland were removed automatically. A standard data assessment procedure of inspection for incorrect or inconsistent data, cleaning for removal of anomalies, visual inspection and verification, and a recording of the changes made to the stored data was followed. This mainly applied to open ended comment box style questions which gave rise to random or unrelated answers. Furthermore, some respondents noted contradictory or unrealistic answers such as ten or more of each car type at their household. After these quality checks, 15 respondents were removed from the data set.

Table 6
Demographics of survey respondents. Source, authors.

		N	%
Jurisdiction	Republic of Ireland	1013	73.8
	Northern Ireland	360	26.2
Age range	18–24	192	14.0
	25–34	287	20.9
	35–44	264	19.2
	45–54	219	16.0
	55–64	196	14.3
	65+	215	15.7
Gender	Male	679	49.5
	Female	691	50.3
	Other	3	0.2
Employment	Full time	662	48.2
	Part time	183	13.3
	Self employed	54	3.9
	Unemployed	163	11.9
	Retired	239	17.4
	Student	72	5.2
Dwelling type	Terrace	227	16.5
	Semi-detached	413	30.1
	Detached	523	38.1
	Apartment	201	14.6
	Mobile home	9	0.7
Annual income before tax (Currency value in Pounds for respondents in Northern Ireland and Euros for respondents in Republic of Ireland)	Less than 11,000	132	9.6
	11,000–25,999	326	23.7
	26,000–50,999	453	33.0
	51,000–75,999	190	13.8
	76,000–100,000	126	9.2
	Greater than 100,000	42	3.1
	Prefer not to answer	104	7.6
Location	City centre	310	22.6%
	Suburban	663	48.3%
	Rural	400	29.1%
Province of ROI residents	Munster	290	28.6%
	Leinster	540	53.3%
	Connacht	120	11.8%
	Ulster	63	6.2%
Area for NI residents	Belfast	156	43.3%
	Rest of Northern Ireland	204	56.7%

The most critical point in delivering a survey is usually to gain people's attention and to be possibly appealing enough to engage their curiosity and encourage them to spend some time completing it. Thus, participants were engaged with a three-line brief on the scope of the study. Participants were informed with accessible information, and specific knowledge on energy was not required, while an informal tone was adopted for multi-answer questions.

The objectives of this survey were to:

- Assess the level of concern with carbon footprint and climate change.
- Measure household expenditure on electricity and heating.
- Assess the level of concern domestic consumers have with rising energy bills.
- Assess the willingness to adopt new energy management strategies and technologies.
- Assess the existing knowledge of renewable energy technologies.

4.2. Demographics of respondents

Table 6 below details the full demographic of respondents from the survey.

Data was collected from 1,373 respondents, all residing on the island of Ireland. The dataset was split into respondents from NI and ROI to grasp the different energy emotions between the two jurisdictions. Fig. 2 highlights respondent location by province on the island of Ireland. The sample used for the survey had quotas for age, gender and location to ensure representativeness; however, we cannot guarantee representativeness for other categories such as employment status or income.

4.3. Statistical analysis

SPSS (Statistical Package for the Social Sciences) statistical analysis software was used for data transformation, analysis and results graphing ("SPSS Statistics Software, 2023). The survey was formulated to contain mainly Likert scale ordinal variables and continuous variables. Some categorical variables exist for demographics questions such as employment status and dwelling type. Therefore, the main statistical tests used were Spearman's rank correlation and Kendall's rank correlation. These are both non-parametric tests which measure the monotonic relationship between two variables. Chi-square tests and Cramer's V tests were also used when analysing relationships between two or more categorical variables. Pearson's correlation was used in instances where the variables being compared were both continuous.

Spearman's rank correlation coefficient is used to test the strength of

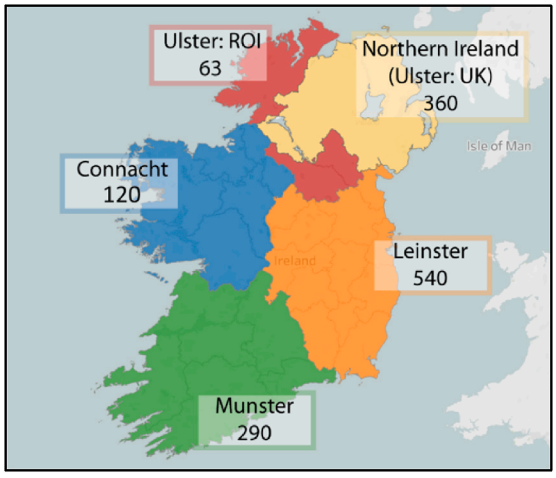


Fig. 2. Respondent location by province on the island of Ireland.

the association between two ranked variables, or one ranked variable and one continuous variable. Similarly, Kendall's correlation is a non-parametric test for ranked variables. In this work we used it to measure the correlation between Likert scale responses and demographic data such as age and income. Chi-square is a measure of statistical significance. It establishes if there is a relationship between a dependent variable and an independent variable. Cramer's V is a measure of substantive significance; essentially how strong the relationship appears to be. These tests were used for nominal data such as heating fuels and primary residence type. All significance tests are conducted at the 0.05 level. In this case we used Sig(two-tailed) p-value.

4.4. Research limitations

This study's main limitation lies in the mere fact that this was an online survey. We argue this represents a limitation because there is no practical way of identifying or describing the population that have responded to the survey. Furthermore, they are only accessible by those who are literate, have access to the internet and are to some degree interested in the subject. This can lead to skewed results because it is challenging to know the motives of those who responded or understand the extent of the bias. For example, energy consumers who are more affected by rising energy bills may be more likely to respond to this survey. However, online surveys in energy systems research are common practice in recent times (Balzan-Alzate et al., 2021), (Watson et al., 2020) and are an effective and accurate way to obtain information from a target profile of respondents ("10 Advantages of Online Surveys, 2023).

Another limitation deals with respondents not accurately recalling information or may not wish to present themselves unfavourably. Nevertheless, throughout the survey design, minimising response bias was an important aspect and emphasis was placed on maintaining participant engagement by structuring the questions as scales or multiple choice. However, the survey was quite long due to the wide scope and there is still a risk of respondent fatigue resulting in random answers in later questions. We reviewed the questions, highlighted areas that could result in erogenous answers or contradictions, manually screened the data and removed outliers.

Table 7
Annual expenditure on electricity and heating across the Island of Ireland (N = 1,373). Source, authors.

	Expenditure	NI [£]	ROI [€]	Island wide
Average annual combined gas and electricity bill for customers with bundled energy tariffs	<900	8%	7%	7%
	900–1300	30%	23%	24%
	1300–1900	16%	26%	24%
	1900–2200	20%	18%	19%
	2200–2700	11%	16%	15%
	2700–3100	5%	5%	5%
	>3100	11%	4%	5%
Average annual electricity bill for customers on an individual tariff	<750	38%	10%	19%
	750–1000	29%	23%	25%
	1000–1250	20%	26%	24%
	1250–1500	10%	21%	18%
	1500–1750	2%	8%	6%
	1750–2000	0%	5%	4%
	>2000	1%	6%	5%
Average annual heating bills	<900	27%	20%	22%
	900–1300	35%	29%	31%
	1300–1900	21%	26%	25%
	1900–2200	7%	13%	12%
	2200–2700	5%	6%	6%
	2700–3100	2%	4%	3%
	>3100	3%	2%	2%

Table 8
Primary heating fuel (N = 1,373). Source, authors.

Fuel type	NI	ROI	Island wide
Heating oil	54%	46%	49%
Electricity	10%	21%	18%
Gas	35%	16%	22%
Coal	1%	8%	6%
Wood	0%	4%	3%
Peat	0%	4%	3%

5. Results and analysis

This section presents the results and analysis of the survey questionnaire. These are divided into three subsections, energy supply and expenditure, climate change and low carbon technologies, and energy conservation behaviours. Please note that the results of this study relate specifically to the case study region and the representative sample.

5.1. Energy supply and expenditure

Respondents were asked about their annual expenditure on electricity and heating, concerns over rising energy bills, and suppliers and supplier switching. Table 7 summarises expenditure on energy across the island. In NI 21.2% of respondents stated that their electricity and gas bills were bundled (i.e. provided by a single company) compared to 37.7% in ROI.

Respondents were asked to select the primary heating fuel used in their dwelling. As can be seen in Table 8, 49% of respondents reported heating oil, 18% reported electricity, 22% reported gas, and the remainder was made up of coal, wood and peat. This shows how a large contingent of households in Ireland are still using fossil fuel heating systems and the transition to electrified heating will require a greater effort across both jurisdictions.

When assessing the relationship between primary heating fuel and the respondents dwelling type and location, Chi-square and Cramer's V tests were used. Table 9 demonstrates the comparison between these statistical tests for both NI and ROI. These tests show that strong associations exist between the variables, all of which are statistically significant at the 95% confidence level. A possible explanation for why rural dwellings are more prone to use oil is because this fuel represents a cheaper option, and in many cases, in the island of Ireland, gas infrastructure is lacking in remote locations. In contrast, gas is a prominent fuel in suburban areas because the high building density justifies the deployment of gas network infrastructure which allows more convenience for home heating (Central Statistics Office, 2021). Similarly, the research shows apartments and terrace dwellings tend to use electric, or gas heating systems compared to detached and semi-detached.

When asked, 'Have you ever struggled to pay for your energy bills?', with examples such as having to borrow money to make payments or a supplier contacting regarding disconnection, 17% of respondents across the island are experiencing a struggle all the time and less than 50% reported that they have never struggled to pay for their energy. Table 10 displays a breakdown of the results for NI, ROI and island wide for this specific question. A similar survey conducted by Uswitch in November 2016 outlined how 32% of families have experienced a struggle to pay their energy bills (Eyre, 2016). These results indicate that a substantial percentage of the sample is experiencing energy poverty to a certain extent and degree. Due to the increased energy prices emerging from the Russian conflict, we suggest that the percentage of households struggling to pay for their energy services could have increased in the past months, exacerbating the vulnerabilities of already vulnerable households.

As observed in Table 11, Spearman's ρ tests and Kendall's τ tests show a moderately strong and statistically significant correlation that in NI as you get older, the struggle to pay energy bills reduces. However,

Table 9
- Relationship between primary heating fuel and primary residence type and location. **Source, authors**.

Relationship between primary heating fuel and dwelling type and location						
	NI			ROI		
	Chi Squared	Cramer's V	P value	Chi Squared	Cramer's V	P value
Dwelling type	56.643	0.223	<0.001	227.690	0.300	<0.001
Location	58.304	0.320	<0.001	162.953	0.359	<0.001

Table 10
– Respondents' experiencing a struggle to pay energy bills (N = 1,373). Source, authors.

Frequency of struggle to pay energy bills	NI	ROI	Island wide
All the time	18%	17%	17%
One or two occasions in the last five years	15%	26%	23%
Only during the winter	11%	13%	13%
Never	57%	44%	48%

existing literature on rising energy costs in Ireland suggests that older, rural households are most affected due to expenditure patterns (Economics and Social Research Institute, 2022). Our results, therefore, contest previous studies, suggesting that the older population are not always at-risk of experiencing energy poverty. Nevertheless, we consider this group extremely vulnerable to the effects of energy poverty. In ROI although the test is statistically significant, there is only a weak correlation. You would expect to find a strong correlation between income and the struggle to pay energy bills (Department for Business, 2021), (Barrett et al., 2022); however, there is a weak correlation and statistically insignificant results in both jurisdictions.

When asked, 'Since the start of the gas and fuel price crisis in Ukraine, are you concerned about your electricity and heating bills?', 53% of respondents reported feeling concerned all the time, with an additional 26% feeling concerned about how they will pay bills during the winter. Meanwhile, only 5% reported never feeling any concern. Table 12 highlights a breakdown of the results for this particular question. These results should take more relevance when, for instance, only in the UK, electricity prices have increased by 36% from 2021 to 2022 and household energy bills have increased by 54% in 2022 alone. In the Republic of Ireland, on the other hand, residential electricity bills will increase by 10.9% and gas bills by 29% in August 2022, in addition to the residential gas price increase of 29% already experienced.

Fig. 3 highlights the key electricity and gas suppliers across NI and ROI. Clearly, in NI, SSE Airtricity, Power NI and Firmus Energy are the most popular suppliers. In ROI, Electric Ireland is the front runner for electricity supply while Bord Gais Energy has the majority market share for gas supply.

Respondents were asked to rate the statements in Fig. 4 regarding their experience with switching electricity suppliers. Fig. 5 shows that the most agreed-upon reports concerned cost savings and switching ease. The latter element also demonstrates that switching providers remains a struggle despite the campaigning efforts conducted in the UK. Indeed, The Guardian recently documented that despite being a savvy energy consumer, switching providers is not as simple as it looks. In fact, the same article documents that consumers can "*run into a whole range of problems*", ranging from building unfair credit balances to acquiring new debt.

5.2. Climate change and low carbon technologies

Respondents were asked questions about their eco-credentials, climate change and their thoughts and willingness to adopt low carbon alternatives for power, heat and transport. It can be seen in Table 13 how 67% of respondents reported some level of concern for their carbon footprint, with an alarming 8% displaying no concern at all. This means that close to 10% of our sample is more likely to keep their lifestyles and not change their behaviours and adopt pro-environmental ones in response to climate change. In other words, while most of our sample is concerned about their carbon footprint, the remaining 8% ignore their carbon footprint's influence on the world.

Spearman's ρ tests and Kendall's τ tests show a weak but statistically significant correlation that younger people in NI are more concerned with their carbon footprint. Although statistically significant, no correlations exist for income. Table 14 provides statistical information for both regions for this question.

When asked about concern over the dependency on fossil fuel imports on the Island of Ireland, the results follow a similar trend to the previous question on concern over carbon footprint. 76% reported concern over fossil fuel imports, with results spread similarly across both NI and ROI. This high percentage of concerned respondents is likely attributable to fossil fuel imports dominating Ireland's energy supply. A 2022 report by Ireland's Sustainable Energy Authority states that 84% of energy consumption is for coal, oil and gas, and only 12% for renewables (Sustainable Energy Authority of Ireland, 2022b). The growing dependence on imported gas and traditional fuels, moreover, constitutes an energy security issue. In this vein, renewables can provide an option, usually a local source of electric power and substitute electricity demand by direct heat production. Renewables, furthermore, often augment the diversity of electricity sources, and through local generation, they contribute to the system's flexibility and resistance to central shocks. Perhaps, individuals would be more willing to integrate renewables into their energy mix if they knew that these sources could combat energy insecurity nationally. Table 15 demonstrates the percentage-based

Table 12
- Respondents' concern for future electricity and heating bills since the start of Ukraine's gas and fuel price crisis (N = 1,373). Source, authors.

Concern for future electricity and heating bills since the energy crisis	NI	ROI	Island wide
All the time	48%	55%	53%
Not very often	16%	15%	15%
I will be in the winter	27%	26%	26%
Never	9%	3%	5%

Table 11
Correlations between the ability to pay energy bills with age and income. Source, authors.

	Have you ever struggled to pay your energy bills?					
	NI			ROI		
	Kendall's tau	Spearman's Rho	P value	Kendall's tau	Spearman's Rho	P value
Age	0.424	0.504	<0.001	0.215	0.262	<0.001
Income	−0.017	−0.23	0.667	0.027	0.033	0.291

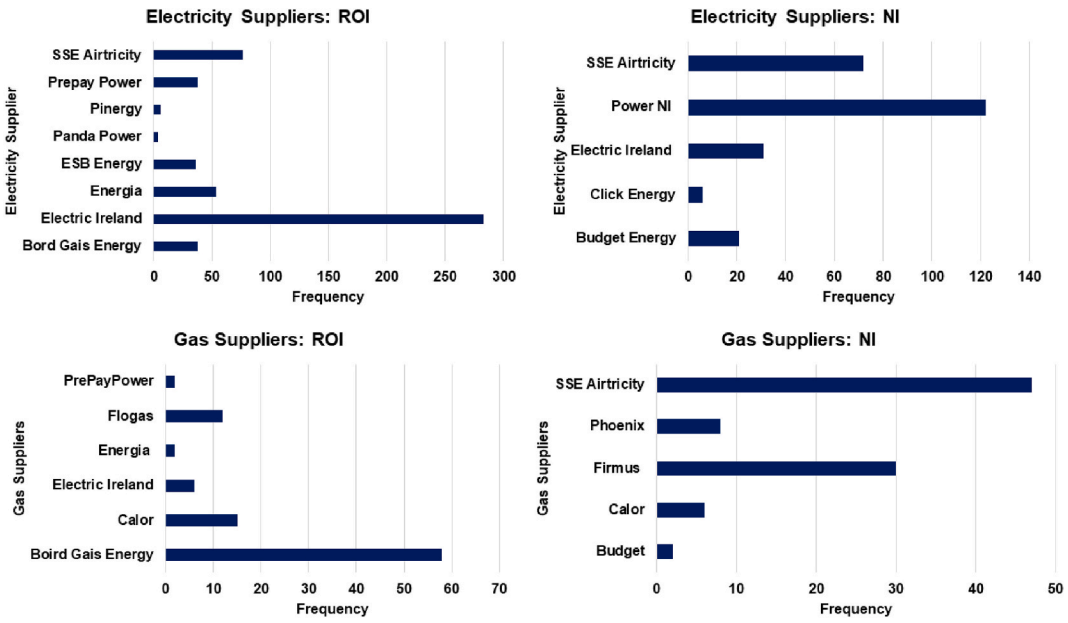


Fig. 3. - Electricity and gas suppliers for NI and ROI customers. Source, authors.

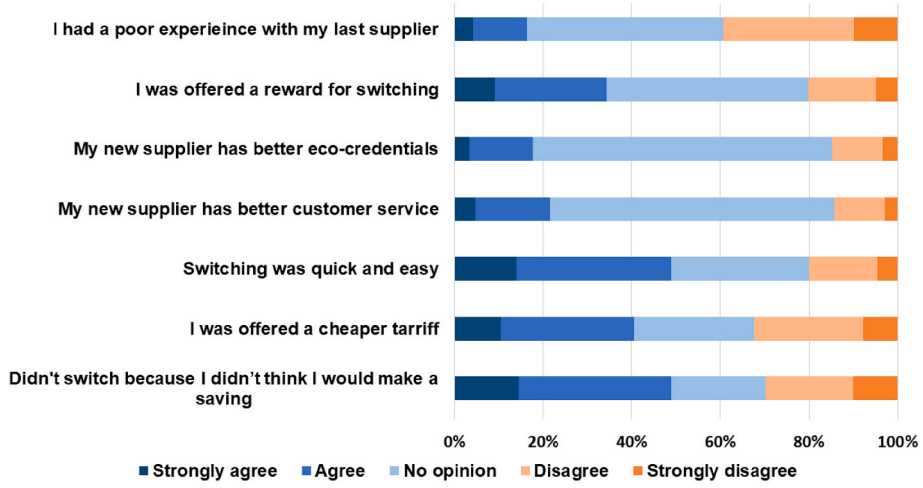


Fig. 4. - Likert scale responses to electricity supplier switching statements. Source, authors.

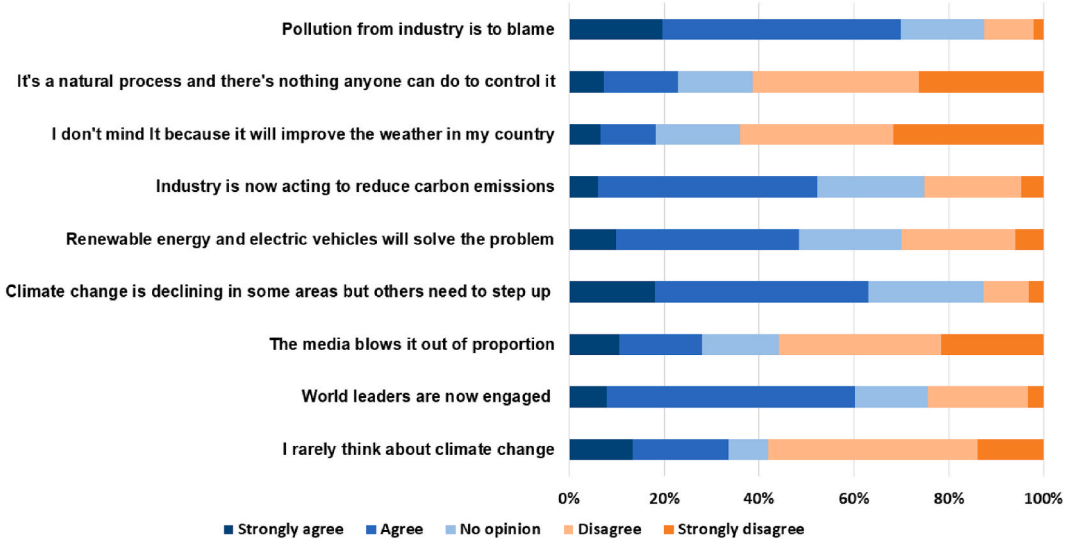


Fig. 5. Likert scale responses to climate change statements. Source, authors.

Table 13
Respondents' concern about personal carbon footprint (N = 1,373). Source, authors.

Concern about personal carbon footprint	NI	ROI	Island wide
Strongly concerned	16%	19%	18%
Concerned	46%	50%	49%
I haven't thought about it	29%	24%	25%
Not concerned at all	9%	8%	8%

results for both regions and island-wide.

Under the Solid Fuel and Natural Gas Carbon Tax and the Mineral Oil Tax Carbon Charge, the government sets a price which emitters must pay for each ton of greenhouse gas emissions emitted. Consequently, this increases the cost of fossil fuels, electricity and other services. As seen in Table 16, when asked how much they would be willing to pay in support of such a policy, 74% of respondents selected the band £0–100, suggesting the vast majority would not support this policy if it was to disadvantage them financially. This corroborates with a similar piece of research conducted by the Climate Engagement Partnership in the UK which suggested that the general public support the majority of net zero taxation policies unless there is a personal cost, with approximately 30% in support even if there are potential financial implications for them personally (Ipsos, 2021). Certainly, our study notes that although consumers may be willing to support green practices through taxation, there can be wide discrepancies in real life, including consumers who may refuse to pay even 1 per cent more for a green service.

Fig. 5 presents results from a Likert scale style question which ranks respondents' level of agreement with various general statements on climate change. From this Figure, we can see how a majority of respondents feel industry is the main contributor to carbon emissions while also playing a key role in acting to reduce emissions. Almost half of the respondents believed that renewable technologies and electric vehicles are the solutions. Around a third claim they rarely think about climate change which validates our earlier question on concern for personal carbon footprint where 33% of respondents across the island showed either no thought or no concern. This varies slightly to a consumer research survey conducted by Ofgem in 2020 which found that 19% of survey resondents showed little to no concern over climate change and their personal carbon footprint (Ofgem, 2020).

District heating involves the centralised generation of hot water and then distribution via an insulated pipe network to the buildings within a city. Table 17 showcases the percentage-based results for this question. Currently less than 1% of homes are supplied by district heating in Ireland, representing one of the lowest shares of district heating in Europe (Government of I relan d, 2019). Yet with this low penetration of district heat networks on the island it is interesting to see how over 25% of respondents have heard of the term and more again be interested in joining a network. This suggests consumers are not the issue here and the issue lies more so with the deployment of a distribution network and establishment of a heat market to give consumers the option to join.

Table 15
- Concern over dependency on fossil fuel imports on the Island of Ireland (N = 1,373). Source, authors.

Concern about fossil fuel imports	NI	ROI	Island wide
Strongly concerned	28%	32%	31%
Concerned	44%	46%	45%
I haven't thought about it	21%	18%	19%
Not concerned at all	7%	4%	5%

Table 16
- The amount of money respondents would be prepared to pay annually in support of a carbon taxation policy (N = 1,373). Source, authors.

£	NI	ROI	Island wide
0–100	74%	74%	74%
100–500	19%	21%	21%
500–1000	5%	4%	4%
1000+	1%	1%	1%

Table 17
Respondents' familiarity with the terms 'district heating' or 'communal heating'.

Has the respondent heard the term 'communal heating or 'district heating'	NI	ROI	Island wide
Yes	30%	25%	26%
No	70%	75%	74%

Table 18
Interest in joining a district heat network if the option became available.

Interest in joining a district heat network if the option was there	NI	ROI	Island wide
Very interested	26%	28%	28%
Interested	37%	40%	40%
Not very interested	13%	13%	13%
No interest whatsoever	12%	9%	10%
I don't know	13%	9%	10%

Further to this question, we asked how interested they would be in joining a heat network if the option was available. Across the island 68% of respondents reported some level of interest with an approximately even split across NI and ROI. Table 18 showcases the percentage-based results for this question.

Table 19 outlines the cars owned by respondents and is broken down by fuel type. It is clear to see that both jurisdictions are dominated by diesel and petrol cars. The National Travel Survey conducted by the Central Statistics Office Ireland in 2019 outlined how only 1.5% of respondents stated ownership of an EV (Central Statistics Office, 2019). Recent reports for EVs in Ireland do suggest that the number of new

Table 14
Correlation between concern over carbon footprint with age and income Source, authors.

Are you concerned about your personal carbon footprint?						
	NI			ROI		
	Kendall's tau	Spearman's Rho	P value	Kendall's tau	Spearman's Rho	P value
Age	0.211	0.256	<0.001	0.151	0.184	<0.001
Income	−0.141	−0.166	0.002	−0.112	−0.132	<0.001

Table 19
Number of cars by fuel type across the Island of Ireland.

Car fuel type	No. cars	NI	ROI
Petrol	0–1	85%	90%
	2–3	14%	9%
	4–10	1%	1%
Diesel	0–1	91%	83%
	2–3	9%	16%
	4–10	0%	1%
Electric	0–1	99%	98%
	2–3	0%	1%
	4–10	1%	1%
Hybrid	0–1	99%	98%
	2–3	0%	1%
	4–10	1%	1%

registrations is increasing rapidly (Central Statistics Office, 2022).

Respondents were asked about the factors that would influence them to purchase an EV, as seen in Fig. 6. The vehicle price was the highest weighting factor, followed closely by reduced transportation cost. Environmental factors and mileage range showed the least agreement but only to a small extent.

Fig. 7 presents the responses to questions on the support for nuclear energy on the Island of Ireland.

It can be seen how the majority of respondents fall in the opposing

Table 20
Energy efficiency measures in the home. Source, authors.

Energy saving measures in the home	NI	ROI	Island wide
Triple glazing	8%	14%	12%
Double glazing	86%	69%	73%
Programmable thermostat	33%	27%	29%
Solar thermal panels	5%	12%	10%
Weather stripping on windows	14%	16%	16%
Roof insulation	60%	55%	56%
Cavity wall insulation	52%	39%	42%
Radiator pipe insulation	19%	20%	20%
Smart home management system	4%	9%	8%
Condensing boiler	21%	19%	20%
Electric heat pumps	2%	12%	9%

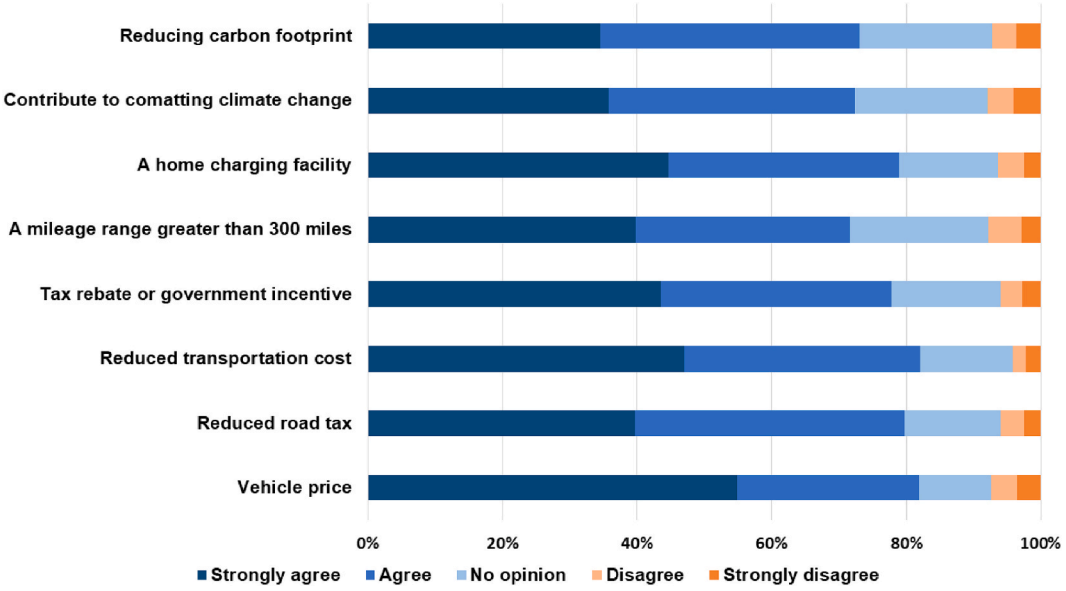


Fig. 6. Factors motivating the purchase of an electric vehicle.

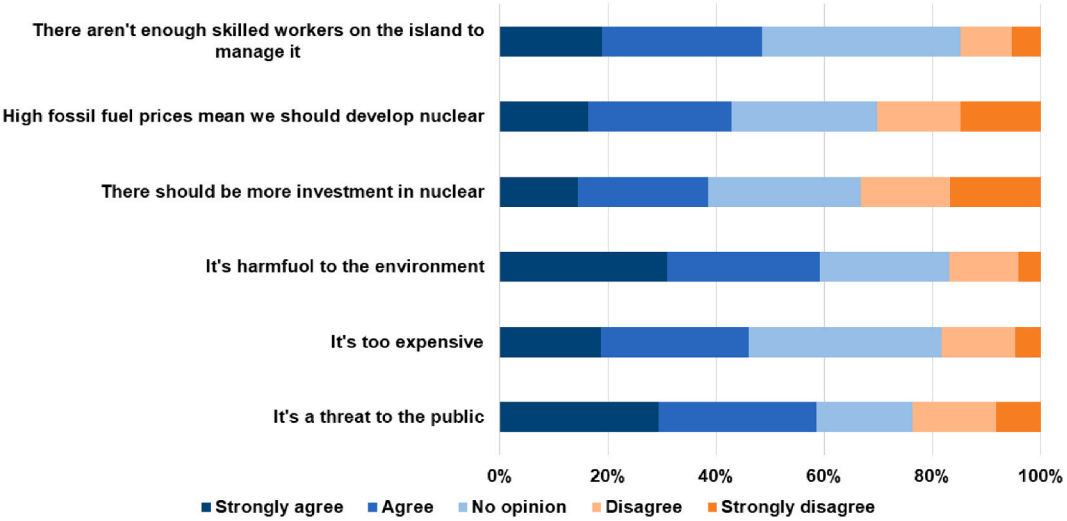


Fig. 7. Likert scale responses to statements on the support of nuclear energy on the Island of Ireland.

category or have no opinion on the subject. Environmental damage and public safety are at the forefront of respondent concerns. A survey commissioned by the Institution of Mechanical Engineers on public perception of nuclear energy found similar results whereby around 25% of respondents were in support of nuclear energy in their local area and around 40% were in opposition (Institution of Mechanical Engineers, 2020).

5.3. Energy conservation behaviours

Questions on energy apps, smart meters, and energy conservation measures in the home were asked to determine concerns and willingness to adopt.

When asked about energy efficiency measures installed in the home, only a small percentage of respondents had solar panels, heat pumps or smart home management devices. In Table 20 we depict that these are less common in NI than in ROI. This is potentially due to the wider availability of grants such as the 'Solar Electricity Grant' and the 'Heat Pump System Grant' for domestic consumers in the ROI. There are currently no grants available for either of these technologies in NI. Statistics for cavity wall and roof insulation suggest that around half of island homes are not properly insulated. A study in (Which?, 2022), suggests that around a third of heat lost in a poorly insulated home escapes through the walls meaning cavity wall insulation is one of the most cost effective measures a household can implement. In relation to window glazing, a combined 85% of respondents have either double or triple glazing suggesting that there are still around 15% of homes with single glazing.

In Fig. 8 we provided a list of common features of energy apps and smart meters and asked respondents to rank these on a Likert scale based on how useful they thought each feature would be. Views were fairly consistent across each, with most respondents in agreement. Allowing the energy supplier to manage time of use for heating and appliances was the only feature with a more mixed response. In previous studies this was also the least preferred feature with respondents expressing concern that third-party control would enable others to monitor everything that occurs in the house and to detect when there is nobody home, enabling criminals to know when the house is empty (Immonen et al., 2020). The most preferred features were the ability to view billing information and monitor energy consumption.

A similar style question can be seen in Fig. 9 where we asked about concerns with adopting new energy technologies. It is clear to see that installation cost, cost recovery and reliability are the key concerns. Responses were more mixed when it came to space, technology experience and data privacy being an issue. We can see how just over 45% of respondents admitted to feeling concerned with sharing their usage profile and other personal details, a similar result to the previous question where 35% of people disagreed to letting their supplier manage time of use. This ties in with the study in (Sovacool et al., 2021b), which suggests a large portion of people feel smart home technologies are intrusive and an invasion of privacy.

6. Discussion

This study explored the understanding of domestic consumer attitudes and behaviour towards energy, with the island of Ireland selected as the case study region. A questionnaire (n = 1,373) was issued in February 2022 focusing on demographics, climate change, renewable technologies, energy supply, expenditure, attitudes and behaviours regarding domestic energy use and energy concerns.

Over the last year, domestic consumers have observed intense volatility in the international energy markets, a cascading effect derived from the expeditious nature of the Coronavirus pandemic economic rebound and the Ukraine-Russia conflict. The consequences of these major events apply not only to the case study region of the island of Ireland but also extend globally. For example, a recent report suggests that the Russia-Ukraine war has nearly doubled household energy costs worldwide (World Economic Forum, 2023). Domestic energy consumers are therefore exposed to record high retail electricity, natural gas and liquid and solid fuel prices and fuel supply issues. Across Europe, the energy and transport poverty challenge has become even more difficult with volatile energy prices (Sovacool et al., 2023). Heightened numbers of people are falling into the energy poverty threshold and a declining economic situation exists in many regions, meaning that employment opportunities are likely diminished. With the number of consumers that are becoming energy vulnerable increasing and higher levels of energy poverty, it is important to recognise the severity of the situation, especially when there are reports that sustained high energy prices could lead to loss of life across Europe that exceeds the actual war casualties (The Economist, 2022), (Foreign Policy, 2022).

As a result of the recent global events and ongoing long-term strategic carbon neutrality objectives, an imperative research question arises: How can researchers, engineers, policy makers and energy system stakeholders create a sustainable, secure and affordable energy future

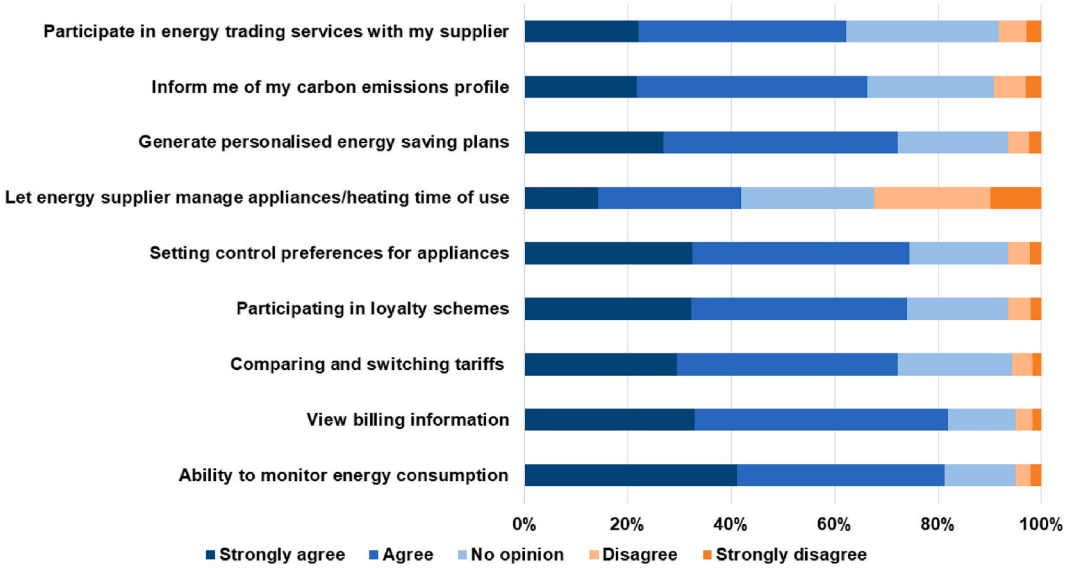


Fig. 8. Likert scale responses to features of energy apps and smart meters.

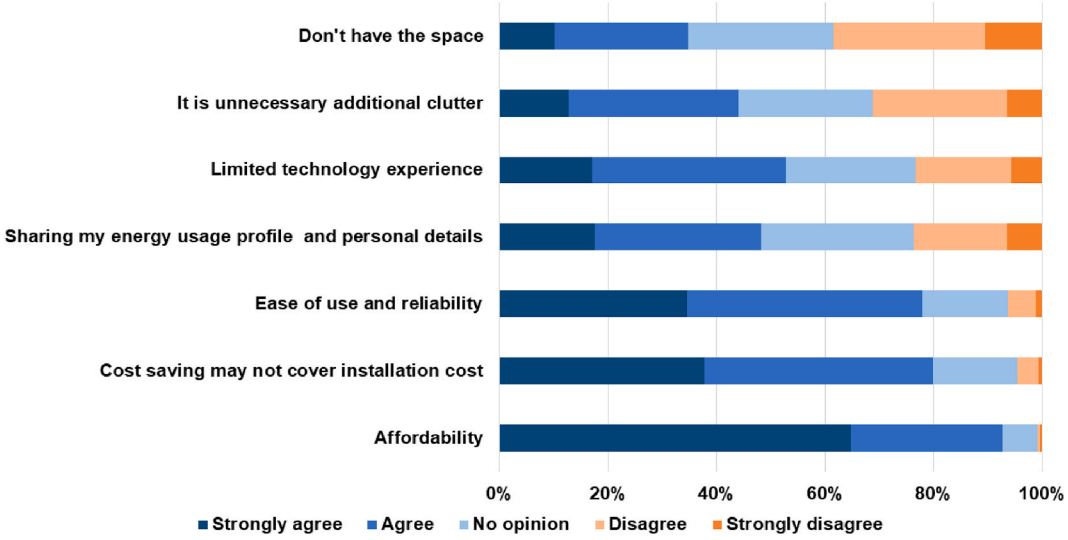


Fig. 9. Concerns about adopting new energy saving technologies.

that serves all consumers, including vulnerable groups? A component of the answer to this question could reside in research by the NI consumer council (Online]. Available, 2022), where they conclude across a range of their publications that the key developments required for such an energy future include influencing consumer behaviours and attitudes and enable informed choices and decision making. Similarly in the ROI, the Commission for Regulation of Utilities (Commission for Regulation of Utilities, 2022) vision statement; "*safe, secure and sustainable supplies of energy and water, for the benefit of customers now and in the future*" underpins the support of domestic consumers during this emerging transformative energy landscape.

The first aim from our research was to establish the level of concern domestic consumers have with their carbon footprint and climate change. Opinions on this subject were similar across both NI and ROI with a majority of respondents stating some level of concern with their carbon footprint. However, 33% of respondents either held no opinion or had no concern over the subject. According to the Office of National Statistics' Opinions and Lifestyle Survey, adults who reported feeling worried about the impact of climate change were three times more likely to have made a lot of changes to their lifestyle in response to the issue (Office for National Statistics, 2021). Our analysis indicated a correlation between younger people and feeling more concerned about carbon emissions and climate change. This is possibly attributable to the younger generation being better educated on climate change issues and engaging more in discussions around global warming through social media channels etc (Pew Research, 2021), (Swim et al., 2022). When asked about concern over fossil fuel imports similar figures exist with around three quarters of respondents feeling concerned with the amount of fossil fuels being imported onto the island.

Interestingly, when the respondents were asked about the potential for nuclear energy to be developed on the island the majority highlighted that they were not in support, regardless of the current high fossil fuel prices. Perhaps the underlying reasons could reside in the fact that nuclear energy has had major historical disastors such as Mile Island in 1979 and Chernobyl in 1986, and any latent concerns with nuclear energy may re-emerge in the event of a nuclear accident being reported in the news ("Climate change or nuclear power). For example, public opinion was improving on nuclear energy many years after the Mile Island and Chernobyl disastors; then the Fukushima disaster occurred in Japan in 2011 (Stoutenborough et al., 2013). Another aspect of nuclear energy which could explain this survey result, includes attitudes towards nuclear waste handling and perceptions that other renewables such as wind and solar power would be sufficient without nuclear (Bisconti, 2018).

The next aim was to establish household expenditure on heating and electricity and then assess domestic consumers' concerns with rising energy bills. Table 7 provides a breakdown of heating and electricity expenses across both jurisdictions. For electricity, approximately 70% of respondents were paying up to £1250; for heating, about 80% were paying up to £1900. In total, 52% of respondents across the island have experienced a struggle to pay their energy bills. This is a significant finding, just over half of the nationally representative sample have experienced a struggle to pay their energy bills. However, surprisingly, there was no correlation when we correlated this data with household income. This finding is supported by research that suggests that a significant proportion of domestic consumers are unable to adequately meet their energy needs but also are not clearly within the definitions of being in energy poverty (Groves and Shirani, 2020). Contrary to our results, we expected higher earners to struggle less to meet payments. However, as energy poverty is a multidimensional issue, factors influencing this circumstance go beyond affordability and income, but other factors such as household energy efficiency and insulation play a key role in the determinants of energy poverty. Throughout our results, energy cost and value for money were recurring themes. Due to the circumstances around the fuel crisis, this is now at the forefront of consumers' energy decision-making, leaving topics such as the environment taking a back seat when choosing a supplier or adopting new technology. Energy bills continued to rise from when this survey was issued, so figures for those experiencing a struggle with bills may have risen. More households have potentially fallen into the vulnerable category and the existing fuel poor households with a low income could be having to do without basic needs such as heat due to the affordability. Therefore, local governments need to take steps to identify those who are in the fuel poor category and deliver support through for example, the Affordable Warmth Scheme in NI to help domestic consumers in the short term.

The implementation of new technologies and emerging business models is a key aspect of harnessing the flexibility of domestic consumers to help manage the demand side of the energy system and combat energy poverty. However, from our results we can see there is a poor uptake of various energy efficient devices and generation technologies. Apart from double glazing and roof insulation, all other options listed, for example, programmable thermostats and smart home management saw less than 50% uptake across the island of Ireland. Digitalisation of monitoring electricity and natural gas usage, via smart metering infrastructure and energy management software, is one

significant way that domestic consumers can make data-driven decisions on energy conservation. When repondents were asked about becoming more interactive with energy apps the responses were positive with many displaying strong agreement with the ability to closer monitor their energy consumption and enable them to generate personalised savings plans. Behaviours relating to energy conservation and energy efficiency are key determinants in reducing high energy bills considering energy prices have been recently increasing consistently. Additionally, energy choice is a major component of ensuring domestic energy costs and personal carbon footprints are reduced and switching providers and tariffs, which provide 'green' pricing arrangements or dynamic time-of-use arrangements, could help in reducing energy cost and carbon emissions.

Ultimately, it is difficult for consumers to control the cascading effects derived from world events that lead to volatility in wholesale energy markets. However, many domestic consumers have control of their day-to-day energy usage and with the assistance of technology and new business models, realising impactful savings on their energy bills is possible. Digital business models such as local energy community-based markets and peer-to-peer energy trading are becoming more prevalent and pervasive, as such models focus largely on benefiting the consumer. Benefits of digital business models over more traditional business models include: 1) Direct access to data which can be analysed to inform bespoke services and offers for consumers. 2) As digital business models are software driven, it often permits shorter lead times to take opportunity of market demands. 3) Improved customer service with an online presence and around the clock support. The issue with some of these data driven approaches is that many consumers are not comfortable with sharing personal details such as their energy usage profile. From our results around half of respondents showed privacy concerns with the adoption of these latest business models which may limit their uptake.

It is important to discuss that, not all domestic consumers can engage with new business models to the same extent and different lifestyles restrict or enhance flexibility to support schemes such as demand response programmes. For example when respondents were asked about their willingness to allow their energy supplier to manage the time of use for heating and certain electrical appliances, around 40% were in agreement. Thus, tiered or variable customer engagement, is an imperative function of new business models where the surplus engagement of select groups of consumers can help support and offset the lack of engagement from consumers which for many different reasons cannot support retail energy market initiatives to the same degree, these consumers could be vulnerable groups or those experiencing energy poverty. This is where the role of energy suppliers and energy system regulators is crucial, as the robust implementation of market-based mechanisms to mitigate increasing energy prices, promote customer engagement and protection of vulnerable groups is vital.The rest of the aims targeted by this paper surround assessing domestic consumers' knowledge of renewable energy and energy management strategies and devices and how willing they are to adopt them. We can see in Table 20 how only 10% of respondents across the island have solar thermal panels installed and only 9% have a heat pump. In a report by the Sustainable Energy Authority of Ireland, it is noted that between 2018 and October 2020 there were 26,900 heat pumps installed in newly built Irish homes (Sustainable Energy Authority Of Ireland, 2020). It is also suggested that in order to meet targets, the annual number of heat pumps installed in existing homes will need to increase by a factor of 30. The biggest factors dictating these technologies' adoption are affordability and cost recovery based on the most common themes highlighted from the survey. A long term solution to the energy crisis and to avoid something similar happening again is for consumers to become more energy independent.

Employing customer engagement strategies in retail electricity markets could be a substantial first step in helping consumers manage their energy usage and support the energy system (Hampton et al., 2022a), (Hampton et al., 2022b). This would involve a much greater domestic scale energy generation and energy conservation technology deployment. From our results we can see how cost is one of the largest inhibiting factors therefore, governments should be looking at how they can administer support or funding to make the installation of these more attractive and at the same time reduce the emissions from domestic energy use. While it is essential for domestic consumers to consider new technologies such as smart meters, electric vehicles, roof-top solar and energy saving appliances, it is also important to try and adopt broader infrastructure which is benefiting the transition to net-zero in other countries, for example, district heating in Denmark, a country with one of the highest district heating penetration rates. District heating could be an efficient way to reduce costs for domestic consumers over the long-term, once the large initial investment (i.e., costs for heat connection, heat network and thermal storage) is recovered. Benefits of district heating for domestic consumers include lower individual carbon footprint (especially if the heat that is generated would otherwise be wasted and captured via combined heat and power systems), costs savings (district heating systems supply multiple homes and benefit from producing heat more efficiently than individual heating systems such as household boilers) and space savings as a localised boiler is not required.

Our research also notes that half of the domestic properties in Ireland still use oil heating systems, contributing to a large portion of carbon emissions in the country. District heating systems have been proven to work well in urban areas, however, they are not prevalent in Ireland and the UK. This is because a large capital investment is required to establish the distribution infrastructure and the major question at the moment is, 'who will provide the funding and take ownership of the grid assets?'. Also because district heating is not prevalent there is a concern over public acceptance and how the market dynamics would function. The idea of district heating is to enable large scale generation of heat via low carbon sources and also use waste heat from local industry, however, more research needs to be done on how this could be integrated into the Irish energy system. This type of energy delivery works best for high building density, typically in social housing areas where occupants are in the vulnerable or fuel poor category. This could benefit both living standards and reducing carbon emissions from the heating sector. Results from the survey indicate that around 70% of respondents would be interested in joining a network if the option was available. Concerning energy management applications and smart meters, most respondents showed support for a scenario where the energy supplier could take control of when certain appliances are used or for heat settings.

This research along with other similar studies on domestic consumers energy attitudes and behaviours is guiding our understanding of the most effective ways to mobilise consumers to mitigate climate change and take responsibility for their own carbon footprint. Through this study we have highlighted various strategies that domestic consumers can take to reduce their personal carbon footprint. The most obvious is energy conservation behaviours such as switching off appliances when not in use to reduce their overall consumption. Installing low carbon technologies such as solar PV for electricity generation and heat pumps instead of conventional oil boilers to reduce the use of fossil fuels and reduce reliance on the electricity grid. Also, shifting consumption patterns to off-peak times to flatten out the demand curve and reduce the requirement for inefficient high carbon generators to meet peaks in demand.

7. Conclusion and recommendations

In this paper, we have highlighted the knowledge, concerns, conservation and usage habits and expenditure that domestic consumers have about their energy. A survey was issued to 1373 respondents across the island of Ireland in February 2022 with a broad range of energy related topics. The questions asked where a mix of opinion style multiple choice where respondents ranked their level of agreement with the statements provided. There were also questions relating to actual energy expenditure and behaviours in the home. It was clear to see the variation

between their values and material interests and how they actually behaved. For example, a large majority of the cohort favoured EVs, yet only a small portion actually owned one. This again suggests that the public are accepting of the idea of low carbon vehicles, however, the inhibiting factor to actually owning one is the price and the availability of charging infrastructure. Similarly, the vast majority displayed concern with their carbon footprint and the dependency on fossil fuels; however, only a few have moved away from fossil fuel heating systems to low carbon generation.

The island of Ireland is an unique region to select for our study as the energy system incorporates a single electricity market with a dichotomic regulatory regime, namely the I-SEM. The I-SEM is regulated by regulatory bodies from both the Republic of Ireland and Northern Ireland which have a special interest in supporting and making the best decisions for consumers. One of the benefits of the I-SEM is that it permits more flexibility as generators from both regions can submit bids at multiple times through-out the trading day. Furthermore, the I-SEM is necessary for availing of the interconnection to European energy markets, permitting more competition between generators, more access to renewable energy and more benefit to domestic consumers in terms of price and carbon emissions reduction.

Domestic consumers are inevitably going to be at the heart of the energy transition and hence it is vital to understand their decision making process to establish a theory of change. Introduction of tiered customer engagement (i.e., a broad range of energy consumer participation schemes and technologies such as demand response programs, energy choice in terms of pricing structures, smart metering, gamification, local energy markets and personalised energy savings plans) in retail energy markets depending on desired level of participation could pose a means to further educate consumers on the internal workings of the electric utility. Each energy supplier must decide on a strategy which works for them based on the sophistication of the grid and its customers at the time. However, these strategies need to constantly evolve as consumers evolve with for example the 'prosumer' model an impending and undeniable transition.

Supply of financial and informational support of vulnerable groups, especially during escalating energy costs, is something local governments must take much greater steps to provide. Research into policy frameworks and analytical mechanisms which help monitor and improve the lives of those experiencing energy poverty allow the transition to a healthier financial situation and improve their individual carbon emissions reduction metrics.

In (Boardman, 2007), Boardman mentions that the most effective way for market transformation is the combination of policies such as: tough minimum energy standards for homes, lighting and appliances, regulation of utilities, generous financial support through grants, funding and the reform of energy tariffs, and much greater information for the consumers. Based on the findings of this paper, a set of policy recommendation are identified below:

1. Promoting behavioural changes – One of the most effective ways to conserve energy in the residential sector is through behavioural changes. For example change of washing machine temperature or less use of a tumble drier. Installation of intelligent metering systems can help households to control and reduce consumption by providing feedback and suggestions to consumers based on their short term and long term consumption patterns.
2. Decentivising the sale of inefficient technologies – For technologies and appliances in the lower banded efficiency category establishment of a carbon tax relating to the level of inefficiency could be added on to decentivise further sales and make purchasing high energy efficiency appliances more attractive.
3. Financial incentives for replacing old heating equipment – The problem most consumers have with exisiting heating systems is that they are unwilling to transition to low carbon or high efficiency boilers when the exisiting boiler is still working. Therefore if consumers were given a tax rebate or subsidy for removing an existing oil boiler for example and replacing it with a low carbon alternative it may speed up the reduction of fossil fuel consumption in the domestic sector.
4. Grants for installing low carbon technology – Most domestic consumers find the price to be the main inhibitor for the purchase of low carbon technologies such as rooftop solar panels or heat pumps. A grant to cover a proportion of the costs would make these more attractive and within reach for more consumers. Furthermore a susbidied finance package with a low interest rate to spread the cost of heat pumps for example over a period of years would also speed up the deployment of this technology in the home.

CRediT authorship contribution statement

Alastair Brown: Conceptualization, Data curation, Formal analysis, Investigation, Methodology, Validation, Visualization, Writing – original draft, Writing – review & editing. **Harrison Hampton:** Conceptualization, Data curation, Formal analysis, Investigation, Methodology, Project administration, Resources, Supervision, Validation, Visualization, Writing – original draft, Writing – review & editing. **Aoife Foley:** Conceptualization, Data curation, Formal analysis, Funding acquisition, Investigation, Methodology, Project administration, Resources, Supervision, Validation, Visualization, Writing – original draft, Writing – review & editing. **Dylan Furszyfer Del Rio:** Data curation, Formal analysis, Investigation, Validation, Supervision, Visualization, Writing – original draft, Writing – review & editing. **Christopher Lowans:** Data curation, Formal analysis, Investigation, Validation, Visualization, Writing – original draft, Writing – review & editing. **Brian Caulfield:** Data curation, Formal analysis, Investigation, Validation, Visualization, Writing – original draft, Writing – review & editing.

Declaration of competing interest

None of the authors have any formal conflicts of interest to declare.

Data availability

Data will be made available on request.

Acknowledgment

This research is supported by the Department for the Economy (DfE) in Northern Ireland. The views and opinions expressed in this document do not necessarily reflect those of DfE.

References

Almeida, A., Fonseca, P., Schlomann, B., Feilberg, N., 08 2011. Characterization of the household electricity consumption in the EU, potential energy savings and specific policy recommendations. Energy Build. 43 (8), 1884–1894.
Attari, S.Z., DeKay, M.L., Davidson, C.I., de Bruin, W.B., 16 08 2010. Pub. Percept. Energy Consumpt. Savings 107 (37).
Ayub, S., Ayob, S.M., Tan, C.W., 2022. Analysis of energy management schemes for renewable-energy-based smart homes against the backdrop of COVID-19. Sustain. Energy Technol. Assessments 52 (Part B).
Bairrão, D.R., Soares, J., Canizes, B., Lezama, F., Vale, Z., 2022. Retail electricity tariffs for electric vehicles in Europe: a multivariate analysis in 4 European countries. IFAC-PapersOnLine 55 (9), 303–308.
Balzan-Alzate, D., López-Sánchez, J., Blessent, D., 2021. An online survey to explore the awareness and acceptance of geothermal energy among an educated segment of the population in five European and American countries. Geoth. Energy 9.
Barrett, M., Farrell, N., Roantree, B., 2022. Energy Poverty and Deprivation in Ireland. Economics and Social Research Institute.
Bassanelli, S., Vasta, N., Bucchiarone, A., Marconi, A., 2022. Gamification for behavior change: a scientometric review. Acta Psychol. 228.
Belaïd, F., Garcia, T., 06 2016. Understanding the spectrum of residential energy-saving behaviours: French evidence using disaggregated data. Energy Econ. 57, 204–214.
Belton, C.A., Lunn, P.D., 2020. Smart choices? An experimental study of smart meters and time-of-use tariffs in Ireland. Energy Pol. 140 (111243).

Bisconti, A.S., 2018. Changing public attitudes toward nuclear energy. Prog. Nucl. Energy 102, 103–113.
Bishoge, O.K., Kombe, G.G., Mvile, B.N., 2021. Energy consumption efficiency knowledge, attitudes and behaviour. Int. J. Sustain. Energy Plan. Manag. 31, 175–188.
Boardman, B., 2007. Home Truths: A Low Carbon Strategy to Reduce UK Housing Emissions by 80% by 2050. University of Oxford.
Bourgeois, A., Pellegrino, M., Lévy, J.-P., 2017. Modeling and mapping domestic energy behavior: insights from a consumer survey in France. Energy Res. Social Sci. 32, 180–192.
Brophy, B., McCormack, E., Smith, W., Timoney, D., 2021. Interactive, bottom-up model to audit the true per-person energy consumption (direct and embedded) of Irish citizens per annum. Energy Rep. 7, 1025–1045.
Brounen, D., Kok, N., Quigley, J.M., 07 2013. Energy literacy, awareness, and conservation behavior of residential households. Energy Econ. 38, 42–50.
Central Statistics Office, 2019. National Travel Survey 2019.
Central Statistics Office, 2021. Household Environmental Behaviours - Energy Use.
Central Statistics Office, 2022. Vehicles Licensed for the First Time July 2022.
A. M. Coggins, N. Wemken, A. K. Mishra, M. Sharkey, L. Horgan, H. Cowie, E. Bourdin and B. McIntyre, "Indoor air quality, thermal comfort and ventilation in deep energy retrofitted Irish dwellings," Build. Environ., vol. 219, no. 109236.
Commission for Regulation of Utilities, 2020a. Domestic Electricity and Gas Bills in Ireland.
Commission for Regulation of Utilities, 2020b. Domestic Electricity and Gas Bills in Ireland Factsheet.
Cowan, K., Liu, X., 2021. Data driven solar forecasting model for northern,. In: *2021 56th International Universities Power Engineering Conference*: Proceedings.
Cronin, Y., Cummins, V., Wolsztynski, E., 2021. Public perception of offshore wind farms in Ireland. Mar. Pol. 134.
CRU, 2021. Energy and Water Monitoring Report 2020.
Department for Business, 2021. Energy & Industrial Strategy, "Energy Follow up Survey: Household Energy Consumption & Affordability. BEIS.
Department for the Economy, 2022. Energy in Northern Ireland 2022.
Dixon, J., Bukhsh, W., Bell, K., Brand, C., 2022. Vehicle to grid: driver plug-in patterns, their impact on the cost and carbon of charging, and implications for system flexibility. eTransportation 13 (100180).
Eakins, J., Sirr, G., Power, B., 2023. Informally sourced solid fuel use: examining its extent and characteristics of the users in the residential sector in Ireland. Energy Pol. 172 (113293).
Economics and Social Research Institute, 2022. Energy Poverty and Deprivation in Ireland.
Electric Ireland. Electric Ireland announces energy price increases from 1st October 2022," [Online]. Available: https://www.electricireland.ie/news/article/electric-ireland-announces-energy-price-increases-from-1st-october-2022. (Accessed 19 September 2022).
Energy Saving Trust. What is the October price freeze? [Online]. Available: https://energysavingtrust.org.uk/what-is-the-october-prize-freeze. (Accessed 19 September 2022).
Energy Saving Trust. Delivering a new energy strategy for Northern Ireland [Online]. Available: https://energysavingtrust.org.uk/delivering-a-new-energy-strategy-for-northern-ireland. (Accessed 26 September 2022).
European Commission. Energy directives [Online]. Available: https://energy.ec.europa.eu/topics_en. (Accessed 2 November 2022).
Eurostat, 2020. Energy Consumption in Households. European Commission.
Eyre, S., 2016. One in Three Families Struggle to Pay Their Energy Bills. U Switch.
Faiers, A., Cook, M., Neame, C., 2007. Towards a contemporary approach for understanding consumer behaviour in the context of domestic energy use. Energy Pol. 35 (8), 4381–4390.
Foreign policy [Online]. Available: https://foreignpolicy.com/2022/09/20/europe-energy-crisis-economy-emergency-russia-war-ukraine/. (Accessed 8 March 2023).
Frederiks, E.R., Stenner, K., Hobman, E.V., 2015a. Household energy use: applying behavioural economics to understand consumer decision-making and behaviour. Renew. Sustain. Energy Rev. 41, 1385–1394.
Frederiks, E.R., Stenner, K., Hobman, E.V., 2015b. Household energy use: applying behavioural economics to understand consumer decision-making and behaviour. Renew. Sustain. Energy Rev. 41, 1385–1394.
Furszyfer Del Rio, D.D., Sovacool, B.K., Bergman, N., Makuch, K.E., 2020. Critically reviewing smart home technology applications and business models in Europe. Energy Pol. 144.
Furszyfer Del Rio, D.D., Sovacool, B.K., Martiskainen, M., 2021. Controllable, frightening, or fun? Exploring the gendered dynamics of smart home technology preferences in the United Kingdom. Energy Res. Social Sci. 77.
Gaur, A.S., Fitiwi, D.Z., Lynch, M., Longoria, G., 2022. Implications of heating sector electrification on the Irish power system in view of the Climate Action Plan. Energy Pol. 168 (113136).
Gong, Y., Ma, G., Jiang, Y., Wang, L., 2023. Research progress on the fifth-generation district heating system based on heat pump technology. J. Build. Eng. 71.
Government of Ireland, 2019. District Heating: Consultation to Inform a Policy Framework for the Development of District Heating in Ireland. Government of Ireland.
Government of Ireland, 2021a. Climate Action and Low Carbon Development (Amendment) Bill 2021.
Government of Ireland, 2021b. Climate Action Plan 2021.
Government of Ireland, Department of the Taoiseach, 2022. Government Announces Sectoral Emissions Ceilings, Setting Ireland on a Pathway to Turn the Tide on Climate Change.
Groves, C., Shirani, F., 2020. 'The bills are a brick wall': narratives of energy vulnerability, poverty and adaptation in South Wales. Energy Res. Social Sci. 70.
Gunfaus, M.T., Waisman, H., 2021. Assessing the adequacy of the global response to the Paris Agreement: toward a full appraisal of climate ambition and action. Earth System Governance 8.
Guo, Z., O'Hanley, J.R., Gibson, S., 2022. Predicting residential electricity consumption patterns based on smart meter and household data: a case study from the Republic of Ireland. Util. Pol. 79 (101446).
Hampton, H., Foley, A., Furszyfer Del Rio, D., Smyth, B., Laverty, D., Caulfield, B., 2022a. Customer engagement strategies in retail electricity markets: a comprehensive and comparative review. Energy Res. Social Sci. 90.
Hampton, H., Foley, A., Furszyfer Del Rio, D., Sovacool, B., 2022b. Developing future retail electricity markets with a customer-centric focus. Energy Pol. 168.
Hansen, K., Breyer, C., Lund, H., 2019. Status and perspectives on 100% renewable energy systems. Energy 175, 471–480.
Houses of the Oireachtas. Climate action and low carbon development (amendment) Act 2021 [Online]. Available: https://www.oireachtas.ie/en/bills/bill/2021/39/. (Accessed 26 September 2022).
Immonen, A., Kiljander, J., Aro, M., 03 2020. Consumer viewpoint on a new kind of energy market. Elec. Power Syst. Res. 180.
Institution of Mechanical Engineers, 2020. Public Perceptions: Nuclear Power.
Ipsos, 2021. Public Support Majority of Net Zero policies... Unless There Is a Personal Cost.
Irish government: department of the environment, climate and communications. Climate Action Plan 2021, 2021.
ISEA Irish Solar Energy Association, 2021. Shaping Our Electricity Future: Consultation Response.
Kastner, I., Stern, P.C., 10 2015. Examining the decision-making processes behind household energy investments: a review. Energy Res. Social Sci. 10, 72–89.
Kennedy, M., Basu, B., 2013. A study on the implementation of renewable heating technologies in the domestic sector in Ireland with implications on consumers' decision-making. J. Clean. Prod. 44, 133–142.
Kerr, N., Winskel, M., 2022. Have we been here before? Reviewing evidence of energy technology phase-out to inform home heating transitions. Energy Res. Social Sci. 89.
Konisky, D.M., Milyo, J., Richardson Jr., L.E., 30 09 2008. Environmental policy attitudes: issues, geographical scale, and political trust. Soc. Sci. Q. 89 (5), 1066–1085.
Li, G., Li, W., Jin, Z., Wang, Z., 2019a. Influence of environmental concern and knowledge on households' willingness to purchase energy-efficient appliances: a case study in shanxi, China. Sustainability 11.
Li, D., Xu, X., Chen, C.-f., Menassa, C., 2019b. Understanding energy-saving behaviors in the American workplace: a unified theory of motivation, opportunity, and ability. Energy Res. Social Sci. 51, 198–209.
Lopes, M.A., Antunes, C.H., Martins, N., 05 2015. Towards more effective behavioural energy policy: an integrative modelling approach to residential energy consumption in Europe. Energy Res. Social Sci. 7, 84–98.
Lowans, C., Foley, A., Furszyfer Del Rio, D., Caulfield, B., Sovacool, B.K., Griffiths, S., Rooney, D., 2023. What causes energy and transport poverty in Ireland? Analysing demographic, economic, and social dynamics, and policy implications. Energy Pol. 172.
Marien, S., Hooghe, M., 03 2011. Does political trust matter? An empirical investigation into the relation between political trust and support for law compliance. Eur. J. Polit. Res. 50 (2), 267–291.
Marti, L., Puertas, R., 2022. Sustainable energy development analysis: energy Trilemma. Sustain. Tech. Entrepreneurship 1 (1).
Martinsson, J., Lundqvist, L.J., Sundström, A., 09 2011. Energy saving in Swedish households. The (relative) importance of environmental attitudes. Energy Pol. 39 (9), 5182–5191.
McGookin, C., Mac Uidhir, T., Ó Gallachóir, B., Byrne, E., 2022. Doing things differently: bridging community concerns and energy system modelling with a transdisciplinary approach in rural Ireland. Energy Res. Social Sci. 89 (102658).
Meles, T.H., Ryan, L., 2022. Adoption of renewable home heating systems: an agent-based model of heat pumps in Ireland. Renew. Sustain. Energy Rev. 169 (112853).
Mi, Z., Jiang, L., 2023. Household Energy Consumptin and Climate Change: Special Issue. Energy Policy.
Moon, B., 2020. The Role of the Consumer in Achieving Net Zero, vol. 1, p. 10.
Mukai, T., Nishio, K.-i., Komatsu, H., Sasaki, M., 2022. What effect does feedback have on energy conservation? Comparing previous household usage, neighbourhood usage, and social norms in Japan. Energy Res. Social Sci. 86.
National Statistics & Housing Executive, 2016. House Condition Survey Main Report 2016.
Nilsson, A., Wester, M., Lazarevic, D., Brandt, N., 2018. Smart homes, home energy management systems and real-time feedback: lessons for influencing household energy consumption from a Swedish field study. Energy Build. 179.
NISRA. Mid year population estimates [Online]. Available: https://www.nisra.gov.uk/statistics/population/mid-year-population-estimates.
Norouzi, M., Colclough, S., Laureano, J., Gavaldà, J., Boer, D., 2022. Low-energy buildings in combination with grid decarbonization, life cycle assessment of passive house buildings in Northern Ireland. Energy Build. 261 (111936).
Northern Ireland Executive, 2022. Energy Strategy for Northern Ireland: Action Plan 2022.
Office for National Statistics. Population and GDP of northern Ireland [Online]. Available: https://www.ons.gov.uk/economy/grossdomesticproductgdp/bulletins/regionaleconomicactivitybygrossdomesticproductuk/1998to2020. (Accessed 19 September 2022).

Office for National Statistics, 05 11 2021. Data on Public Attitudes to the Environment and the Impact of Climate Change, Great Britain ([Online]).
Ofgem, 2020. Consumer Opinion about Climate Change and Decarbonisation. Ofgem.
Oil Prices. Heating oil prices in Ireland (500 litres) [Online]. Available: https://www.oilprices.ie/. (Accessed 20 September 2022).
OilPrices.ie. Heating oil prices in Ireland [Online]. Available: https://www.oilprices.ie/. (Accessed 2 November 2022).
[Online]. Available: https://www.consumercouncil.org.uk/. (Accessed 1 December 2022).
Perlaviciute, G., Steg, L., Sovacool, B.K., 2021. A perspective on the human dimensions of a transition to net-zero. Energy and Climate Change 2.
Pew Research. Gen Z, millennials stand out for climate change activism, social media engagement with issue [Online]. Available: https://www.pewresearch.org/science/2021/05/26/gen-z-millennials-stand-out-for-climate-change-activism-social-media-engagement-with-issue/. (Accessed 3 August 2023).
Pillai, A., Reaños, M.T., Curtis, J., 2021. An examination of energy efficiency retrofit scheme applications by low-income households in Ireland. Heliyon 7 (10).
Power to switch. Average electricity and gas usage in northern Ireland [Online]. Available: https://powertoswitch.co.uk/average-electricity-and-gas-usage-in-northern-ireland/. (Accessed 19 September 2022).
Rafferty, John, ESB Emerging Technologies and R&D, 2019. The Role of Battery Energy Storage. ESB.
Ruiz, I., Faria, S.H., Neumann, M.B., 2020. Climate change perception: driving forces and their interactions. Environ. Sci. Pol. 108, 112–120.
Rural Energy Ireland, 2019. Rural Heat Demand [Online]. Available: https://www.rural-energy.eu/country-data/ireland/. (Accessed 26 September 2022).
Schuitema, G., Steg, L., 2005. Perception of energy use of domestic appliances. In: Developments in Marketing Research. Yearbook, vol. 2005, pp. 165–180.
Schwartz, D., Bruine de Bruin, W., Fischhoff, B., Lave, L., 2015. Advertising energy saving programs: the potential environmental cost of emphasizing monetary savings. J. Exp. Psychol. Appl. 158–166.
SEM Committee. ISEM go live confirmation update [Online]. Available: https://www.semcommittee.com/news-centre/isem-go-live-confirmation-update. (Accessed 2 November 2022).
SONI, 2021. Shaping Our Electricity Future.
Soni, Eirgrid, 2022. All-Island Generation Capacity Statement 2022-2031.
Sovacool, B.K., Hook, A., Sareen, S., Geels, F.W., 2021a. Global sustainability, innovation and governance dynamics of national smart electricity meter transitions. Global Environ. Change 68.
Sovacool, B.K., Martiskainen, M., Furszyfer Del Rio, D.D., 2021b. Knowledge, energy sustainability, and vulnerability in the demographics of smart home technology diffusion. Energy Pol. 153, 112196.
Sovacool, B.K., Upham, P., Martiskainen, M., 2023. Policy Prescriptions to Address Energy and Transport Poverty in the United Kingdom.
Stawska, A., Romero, N., Weerdt, M., Verzijlbergh, R., 2021. Demand response: for congestion management or for grid balancing? Energy Pol. 148, 111920.
Steg, L., Vlek, C., 2009. Encouraging pro-environmental behaviour: an integrative review and research agenda. J. Environ. Psychol. 29 (3), 309–317.
Steg, L., Bolderdijk, J.W., Keizer, K., Perlaviciute, G., 2014. An Integrated Framework for Encouraging Pro-environmental Behaviour: the role of values, situational factors and goals. J. Environ. Psychol. 38, 104–115.
Stern, P.C., Dietz, T., 2020. A broader social science research agenda on sustainability: nongovernmental influences on climate footprints. Energy Res. Social Sci. 60.
Stern, P., Janda, K., Brown, M., 2016. Opportunities and insights for reducing fossil fuel consumption by households and organizations. Nat. Energy 1 (16043).
Stoutenborough, J.W., Sturgess, S., Vedlitz, A., 2013. Knowledge, risk, and policy support: public perceptions of nuclear power. Energy Pol. 62, 176–184.
Süsser, D., Martin, N., Stavrakas, V., 2022. Why energy models should integrate social and environmental factors: assessing user needs, omission impacts, and real-word accuracy in the European Union. Energy Res. Social Sci. 92.
Sustainable Energy Authority Of Ireland, 2020. Encouraging Heat Pump Installations in Ireland: Strategies to Maximise Heat Pump Installation and the Savings Produced.
Sustainable Energy Authority of Ireland. Energy use overview [Online]. Available: https://www.seai.ie/data-and-insights/seai-statistics/key-statistics/energy-use-overview/. (Accessed 19 September 2022).
Sustainable Energy Authority of Ireland, 2022b. Energy in Ireland. SEAI.
Swim, J., Aviste, R., Lengieza, M., 2022. OK Boomer: a decade of generational differences in feelings about climate change. Global Environ. Change.
The Consumer Council. Home heating oil price checker [Online]. Available: https://www.consumercouncil.org.uk/homeheatingoilpricechecker/tool. (Accessed 20 September 2022).
The Consumer Council. Home heating oil price checker NI [Online]. Available: https://www.consumercouncil.org.uk/homeheatingoilpricechecker/tool. (Accessed 11 February 2022).
The Economist. High fuel prices and Russia Ukraine war [Online]. Available: https://www.economist.com/interactive/graphic-detail/2022/11/26/high-fuel-prices-could-kill-more-europeans-than-fighting-in-ukraine-has. (Accessed 8 March 2023).
The Northern Ireland Protocol, 2020. Cabinet Office.
The World Bank, Ireland, G.D.P. [Online]. Available: https://data.worldbank.org/. (Accessed 19 September 2022).
Trinh, K., Fung, A.S., Straka, V., 2021. Effects of real-time energy feedback and normative comparisons: results from a multi-year field study in a multi-unit residential building. Energy Build. 250 (111288).
Uidhir, T.M., Rogan, F., Collins, M., Curtis, J., Ó Gallachóir, B.P., 2020. Improving energy savings from a residential retrofit policy: a new model to inform better retrofit decisions. Energy Build. 209, 109656.
UK Government, 2021. Net Zero Strategy. Build Back Greener.
Uk Government Dep. for BEIS, 2022. 2021 UK Greenhouse Gas Emissions.
United Nations Development Programme, 2022. Human Development Report 2021/2022.
UREGNI, 2021. Annual Retail Energy Market Monitoring Report Period: January – December 2020.
U.S. Department of Energy, NREL, July 2000. Elements of an Energy-Efficient. House DOE/GO-10200-1070 FS2-207.
Utility Regulator, N.I., 2022. Conclusion of the Utility Regulator's Review of the Power NI Ltd Maximum Average Price.
Valkengoed, A.v., Steg, L., Perlaviciute, G., 2021. Development and validation of a climate change perceptions scale. J. Environ. Psychol. 76, 101652.
Watson, N.E., Huebner, G.M., Fell, M.J., Shipworth, D., 2020. Two energy suppliers are better than one: survey experiments on consumer engagement with local energy in GB. Energy Pol. 147 (111891).
Werff, E.v. d., Perlaviciute, G., Steg, Linda, 17 06 2015. Understanding the human dimensions of a sustainable energy transition. Front. Psychol.
Which?, "Cavity Wall Insulation Costs and Savings," Which?, 2022.
World Economic Forum. Russia - Ukraine energy costs [Online]. Available: https://www.weforum.org/agenda/2023/02/russia-ukraine-war-energy-costs/. (Accessed 8 March 2023).
Yunusov, T., Torriti, J., 2021. Distributional effects of Time of Use tariffs based on electricity demand and time use. Energy Pol. 156 (112412).
10 Advantages of online surveys [Online]. Available: https://www.smartsurvey.co.uk/articles/10-advantages-of-online-surveys. (Accessed 6 March 2023).
Climate change Act (northern Ireland) 2022 [Online]. Available: https://www.legislation.gov.uk/nia/2022/31/contents/enacted. (Accessed 26 September 2022).
Climate change or nuclear power—No thanks! A quantitative study of public perceptions and risk framing in Britain," Global Environ. Change, vol. 18, no. 1.
Commission for Regulation of Utilities: Strategic Plan 2022 - 24, 2022.
Generating renewable electricity - solar panels [Online]. Available: https://energysavingtrust.org.uk/advice/solar-panels/. (Accessed 18 May 2023).
Ireland population Growth rate 1950-2023 | MacroTrends [Online]. Available: https://www.macrotrends.net/countries/IRL/ireland/population-growth-rate.
Quick Guide to the Integrated Single Electricity Market, 2016. Eirgrid.
SPSS Statistics software [Online]. Available: https://www.ibm.com/products/spss-statistics. (Accessed 8 March 2023).
System and Renewable Data Summary Report: Fuel Mix & CO2, 2021. Eirgrid.
The Potential of Behavioural Interventions for Optimising Energy Use at Home, 2021. IEA.
The potential of behavioural interventions for optimising energy use at home [Online]. Available: https://www.iea.org/articles/the-potential-of-behavioural-interventions-for-optimising-energy-use-at-home. (Accessed 19 January 2022).