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Evaluating gaps in knowledge, willingness and heating performance in individual preferences on household energy and climate policy: Evidence from the UK.

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ABSTRACT

This study investigates the knowledge-willingness, willingness-performance, and knowledge-performance gaps regarding reducing carbon dioxide emissions and emerging technologies of the 2137 British residents. Household's heating sources and heat settings are anticipated as key criteria for evaluating respondents' performances. The study revealed more than 80% of respondents have a good knowledge regarding climate change and carbon issues. The study found a smaller gap in knowledge versus willingness as 59%, 87%, 88% and 85% of respondents want to use bioenergy, afforestation/reforestation, solar and wind for their future energy sources. The Multinomial logit regression (MNLR) investigates that incrementing good and very good knowledge index increases the odds of a high willingness to save energy by 33% and 6%, respectively. The willingness versus performance study identified 96% as claiming to be more likely energy savers, whereas, in reality, 52% of them never or rarely took basic measures like setting their heating system to turn off. Despite having a good and very good knowledge index, the knowledge versus performance appears, 75% of respondents are using gas boilers and gas central heating. Policymakers and the research community need to develop comprehensive plans by taking these wider social issues to meet net-zero targets. Employing smart building principles, lowering the installation costs of the new smart technologies, awarding and encouraging the energy saver, setting individual carbon footprint limits, and training and empowering household representatives to select better energy for houses could popularise the emission reduction technologies in the UK.

1. Introduction

According to the Intergovernmental Panel on Climate Change [1], to keep temperature to 1.5°C level globally, countries need to quickly reduce their carbon dioxide (CO_2) emissions and to that end many have begun to adopt net-zero targets by mid-century [2].

Several issues are significant in reducing carbon emissions. Household consumption habits can contribute to carbon emissions reductions in our daily lives. According to Ivanova et al. [3], household's consumption is mostly (60%) responsible for the transpiring of global greenhouse gas (GHG) emissions. Hertwich and Peters [4] identify that household consumptions are responsible for emitting 72% of global GHG emissions. Therefore, it is crucial to estimate households' knowledge, willingness and performance on energy consumption in their daily lives to save energy and/or combat climate change.

Several policies, agreements and technologies have been adopted in recent decades. With global agreements, it is also essential to implement national policies and raise people concerns to consume negative emission-based products to mitigate climate change issues. Saving energy, using renewable energy, reducing the wastage of natural resources (e.g., water), changing food habits, purchasing local products and following proper waste management systems can reduce carbon emissions and save the environment.

The best natural solutions for reducing carbon emissions are planting trees, maintaining and preserving coastal ecosystems, restoring peat bogs and increasing aquatic plants and the seashore [2]. However, the natural carbon emissions reduction process is quite time consuming; only the application of technologies can reduce carbon immediately. Hence, this study is focused on carbon because, at the moment, among all the greenhouse gases, it is only possible for carbon dioxide to reach the level of negative emissions [2]. The term negative emissions are

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Abbreviations

CO_2	Carbon dioxide
CCS	Carbon capture and storage
CNAA	Council for National Academic Awards
DV	Dependent variable
GKI	Good knowledge index
GHGs	Greenhouse gases
IV	Independent variable
PKI	Poor knowledge index
MNLR	Multinomial logit regression
VGKI	Very good knowledge index

more than reducing. This process extracts carbon from the atmosphere and stocks it where it remains away from the atmosphere. Several technologies create negative carbon, for example, bioenergy with Carbon Capture and Storage (CCS) also known as BECCS [5]. The CCS technology prevents up to 90% of CO_2, generated from fossil fuels for electricity or other processes, from entering the atmosphere and capturing it [5]. Thus, the CCS process has three stages: capture, transport and store carbon dioxide. The capturing process separates CO_2 from other gases and transports it by pipe or in different ways to the storage location [6].

A combined approach is necessary to remove carbon emissions from the atmosphere, the implementation and adaptation of policies, natural treatments and growing people's consciousness. Public awareness and willingness is supported by knowledge, whether that knowledge is backed up by education, experience, social media or networking. Defining knowledge is quite difficult as it is an intangible product. Researchers have tried long to define knowledge in different ways, nonetheless the concept is still contested [7]. A survey of Australian respondents found people lacked knowledge or interest in CCS technology and were unwilling to learn about it [8]. The study by Rahman et al. [9] about Finnish forest stump harvesting for bioenergy production indicates that 70% of the respondents have very good knowledge concerning stump harvesting but held quite critical perceptions concerning stump harvesting for bioenergy production.

Despite supporting saving energy, some might lack knowledge about GHG emissions and its contribution to climate impacts. Furthermore, despite having knowledge, some people are unwilling to reduce their carbon footprint. Letwin et al. [10] found that even though many people are concerned about the environment and climate issues, not stepping forward to reduce their daily domestic energy consumption. Frederiks et al. [11] noted that despite having enough knowledge about saving energy, many consumers just fail to attain energy efficiency in their consumption. In a survey of 544 households in the Philippines regarding the knowledge, attitude and practices concerning climate change, respondents had very low affirmation with willingness-to-pay (WTP) [12]. However, it might be a lack of their self-reported knowledge or observed capability that further failed to motivate or grow their intentions to save energy. According to Frederiks et al. [11], this state is called the 'knowledge-action gap' and 'value-action gap'.

Thus, it is also important to identify the determinants of consumer knowledge and its relationship with their WTP [13]. Huang [14] and Sanjuán et al. [15] identify consumer knowledge as an explanatory variable in consumer WTP analysis. Schwirplies et al. [16] identify young, female and high-income respondents as being more willing to offset carbon emissions from travel. A survey-based study about consumers' WTP for organic food products revealed that socio-economic status, lifestyle, environmental and health issues are significant in their differences regarding WTP [13]. Letwin et al. [10] reveals that behavioural comparisons concerning energy use encourages consumers to limit their energy consumptions. Furthermore, a study concerning carbon emission trading schemes in China identifies that the companies perception concerning energy costs might influence the companies' WTP for carbon emissions [17]. Social networking groups (friends, colleagues and family members) are vital both as a conduit for gaining greater knowledge and for reinforcing the social norms to reduce energy consumption and save energy [10].

The current research tried to explore the knowledge of the people of the United Kingdom (UK) about current environmental problems, climate change and future carbon technologies, their willingness to utilise proposed technologies like bioenergy, afforestation, energy-efficient appliances, CCS gas power and energy-efficient cars and their likelihood to save energy at home. Thus, this study aims to identify the UK people's knowledge levels, prepare a knowledge index, distribute knowledge index into different regions (i.e., counties), and compare knowledge levels into the willingness and performance level to deploy carbon emissions reduction technologies. Hence, the corresponding study tried to connect the people's knowledge versus performance and willingness versus performance to contribute to climate change issues. The UK is a large economy that emitted 365.7 million tonnes (Mt) of CO_2 in 2018 [18]. Despite this vast amount of emissions, it continues to reduce GHGs and the main component of GHG, i.e. carbon emissions. Thus, the country's 2018 carbon emissions were 2.4% less than 2017 carbon emissions [19], and carbon footprint was 6% less in 2016 than in 2015 [20]. In addition, the UK is the first country to pass the zero emissions law and set a target for 2050 [21,22]. Thus, these reasons encouraged us to study the largest economy of Europe.

The heating system setup and heating sources are considered in the performance study. According to the authors, the insight of these two areas is enough to evaluate people's performance concerning energy saving tendency and awareness about climate change. Specialists and policy researchers identify decarbonising of heat as a significant challenge, as it holds the largest share among the household end-use services [23]. The 2006 Stern Review [24] noted that heat and electricity generation and land-use changes are responsible for 79% of global GHG emissions. In the EU in 2019, 64% of the final energy consumption in the household sector was for space heating [25]. In the UK, about ten years before (including water heating), that was 85% of the total domestic energy consumption [26]. A recent study by AUDE [27] indicated that space heating with lighting accounts for more than fifty per cent of households' energy costs.

Further, a house with gas appliances generates over 6 tonnes of CO_2/ per year compared to an electric appliance house [28]. Currently about 85% of the UK households rely on the gas system [29]; and there, about 74% of heating and hot water demand is fulfilled by natural gas and 10% by liquid petroleum oil [30]. Thus, fossil boilers are the key provision for domestic heating sources there [31].

The remainder of the paper is divided into three sections. First, the methods used in the study are presented in section two, describing questionnaire design, data analysis techniques and the reliability tests taken. Next, this study presents in section three the results of the studies that explore respondents' knowledge about climate change and carbon technologies, the relationship between their knowledge level versus their willingness to deploy different energy technologies and their stated energy-saving performance. The study then develops a multinomial prediction analysis between respondents' knowledge, willingness, and performance. Finally, section four discusses the implications of the study's findings and provide some concluding remarks.

2. Methods

The study methods followed into questionnaire designing to fulfil the research aim, check the missing data, organise and rearrange the data, and reliability test to check the coherence among the questions. Therefore, rating respondents according to their knowledge and prepare knowledge index. Compare respondents' knowledge index with their social grade, educational qualification. Thus, compare respondents' knowledge level with their willingness to deploy different technologies and their performance for energy saving. The Pearson's chi-square test tests the significance of the percentage-based key findings of the analyses to examine the goodness of fit between the predictable and experiential outcomes. Finally, a Multinomial logistic regression (MNLR) will develop to identify respondents Knowledge, willingness and performance relationship. However, all these data checking, organizing and analysis methods followed step by step, represented in detail in the following sections.

2.1. Questionnaire design

Considering the environmental changes experienced in the previous years' and current context, researchers at the University Cambridge have been preparing questionnaires with the help of YouGov Plc GB. In continuation of this, a new questionnaire was modelled in the same way in 2019 by adding CCS technology-related questions in line with the previous year's questions. Therefore, the social survey was conducted by YouGov Plc (a member of the British Polling Council) between 8 and 9 May 2019. Rather than traditional polling, the firmuses internet polling where a panel of electors were engaged through pop-up advertisements or invitations from non-political websites. According to the definition, the sample was selected randomly from the base sample. Thus, a survey link was provided to the sample group and requested them to attend the survey. Then, 2295 adults took part in the survey.

From the 2019's questionnaire, this study picked up climate and carbon emission reduction technology-related questions. The questionnaire (based on selected questions) had a total of 24 mixed (i.e., both in a closed and open-ended) format questions. In the questionnaire, 1–5 are basic questions, 6–13 are knowledge-based questions, 14–15 is about the respondent's willingness to reduce carbon emissions and, finally, questions 16–17 is about respondent's actions or performance in response to his/her knowledge about carbon emissions (Fig. 1). In the basic section, the questionnaire focused on age, gender, region, social grade and educational qualifications. The social status is graded as A and B for intermediate managerial or higher professionals, C1 for administrative, supervisory, junior managerial and clerical occupations, C2 for skilled or manual occupations, and D and E are for semi-skilled, unskilled, unemployed and lowest grade manual occupations [32].

The educational qualifications are divided into a large number of categories in the questionnaire because of differences over time and in different regions of the UK and so they include: no formal qualifications, youth training certificate, recognised trade apprenticeship completed, clerical and commercial, city and guilds certificate, advanced city and guilds certificate, ONC, CSE grades 2-5, CSE grade 1, GCE O level, GCSE, School Certificate, Scottish ordinary/lower certificate, GCE A level or higher certificate, Scottish Higher Certificate, nursing qualification, teaching qualification (non degree), university diploma, university/CNAA first degree (e.g., BA, B.Sc, B.Ed), university/CNAA higher degree (e.g., M.Sc, Ph.D), other technical, professional or higher qualification, don't know or prefer not to say. As the educational categories are mutually exclusive, to compare educational qualifications versus knowledge index, the study considered only three categories: university or CNAA first degree (e.g., BA, B.Sc, B.Ed), university or CNAA higher degree (e.g., M.Sc, Ph.D) and other technical, professional or higher qualification, as these would be relevant to understand knowledge level (and are of a sufficient size).

The sample provides a good quality representative sample, as it maintains balance across all key socio-demographic variables including social class, gender, age group, and educational background across the twelve regions of the UK. Hence the sample size is free from the selection bias problem. It can claim that the decided sample is representative of the target population (Table 1).

2.2. Data analysis method

The missing values of the questionnaire are checked among the 2295 samples. One of the principal aims of this study was to measure respondents' knowledge index. Thus, when a respondent skipped or selected the 'don't know' option in response to a number of questions, estimating their knowledge becomes more difficult, thus those data were removed from the total sample size. Ultimately, 2,137 respondents who answered more than eighty per cent of the selected questions are considered for the final sample.

Questions 6–13 is used to identify respondent's knowledge level, where questions 9–12 were true or false statements. Based on different literature, the authors concluded that, climate change is caused by a hole in the earth's atmosphere (Q9) is false. It is because the ozone hole is not triggering global warming directly although it affects the atmospheric circulation level [33]. Another statement, every time we use coal or oil or gas, we contribute to the greenhouse effect (Q10) is considered true because the coal that is combusted is a type of sedimentary rock which has another name, coal seams. Dead plants decay into peat and as a

Table 1
Distribution of the sample size.

	Information (Percentage)
Gender balance	Male (42.3), Female (57.7)
Random age group	Average age 51
18-89	18-35 (22), 36–45(17), 46–55(16), 56–65(20), >65 (25)
Regional balance	North East (6), North West (10), Yorkshire and the Humber (8), East Midlands (8), West Midlands (8), East of England (9), London (9), South East (11), South West (10), Wales (6), Scotland (8), Northern Ireland (7)

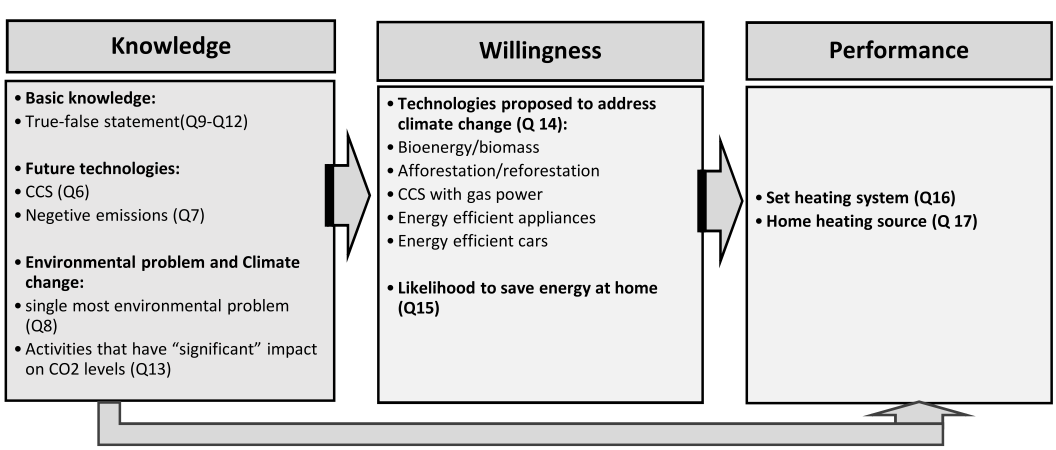


Fig. 1. Questionnaire design.

result of the deep pressure and heat, it turns into coal over the years. However, with other variables (e.g., nitrogen, oxygen, hydrogen and sulfur) coal contain a key ingredient, carbon. After combustion, coal releases carbon dioxide in the atmosphere and causes the greenhouse effect. Furthermore, oxygen is the main component of the smoke emitted from a chimney or exhaust pipe (Q11). Although the emitted gas is dependent on the utilisation sources, this statement is false because whatever may come from chimneys or exhaust pipes, oxygen is not the main component. The last statement, coal is produced from dead plants (Q12), is considered as true, as previously discussed in response to Q10's rationality analysis.

In the willingness section, Q14 was, the given technologies to the respondent were, bioenergy/biomass (producing energy from trees or agricultural wastes), afforestation/reforestation (planting trees to absorb carbon dioxide from the atmosphere), CCS with gas power (capturing carbon dioxide from natural gas-fired power plant exhaust and storing it in underground reservoirs), carbon capture and storage with coal power (capturing carbon dioxide from coal-fired power plant exhaust and storing it in underground reservoirs), carbon capture and storage with bioenergy (capturing carbon dioxide from biomass (wood-fired) power plant exhaust and storing it in underground reservoirs), energy efficient appliances (producing kitchen and household appliances that use less energy to accomplish the same tasks) and energy efficient cars (producing cars that use less energy to drive the same distance). These subgroups are considered as single questions under the main question of question 14 because there was an option for respondent to select all the answers to the question. According to us, authors intuition, all the technologies or any one of the several options can be used by the respondent (Table 2).

In the Performance section, respondents were asked how often, if ever, they reduced their thermostat or set their heating system (Q16) and what was the source of heating in their home (Q17). 95–98% of UK households with central heating used a gas boiler, of which less than 5% (800,000) have no controls over the timing of their heating [34,35]. The analysis was conducted by applying the crosstab to identify respondents' percentages, chi-square test to test the significance level of the analysis and scatter plot matrix to estimate the correlation between the respondents' selection of the two variables. The software package SPSS (Statistical Program for the Social Sciences) 25.0 was utilised to conduct the analysis.

A MNLR model is developed to make a predictions evaluation on the three categories of knowledge indexed respondents willingness and performance level to reduce carbon emission. R v4.0.4 is utilised to execute the analysis [36]. MNLR is an iterative method that is applied when the dependent variable (DV) is nominal (no order in outcome), and independent variables (IV) are needed to predict more than two outcomes. In the MNLR analysis, Knowledge Index (KI) is considered as the independent variable (IV) and Willingness to save energy, Performance_heat set and Performance_heat source are the dependent variables (DV). All the DVs and IV are divided into three classes (1, 2 and 3) where 1 is considered as the reference class.

To quantify the knowledge category and making KI, this study applied the method used by Rahman et al. [9], who followed World Bank's knowledge assessment method (KAM) [37]. Therefore, ranked each question of the knowledge section into a similar rank and identified their average. Then, the average of the knowledge observations is categorised into three groups: poor as <1, good as 1.01–1.15 and very good as >1.5 (Table 3). Therefore, the aim of MNLR is to explore what kind of willingness and performance to reduce carbon emission is executed by particular knowledge indexed respondent.

The MNLR equation for willingness and performance is:

Table 2
Description of the key variables.

Questions	Assigned points
Q6 Familiar with CCS technologies *Q7 Familiar with NETs*	*Never heard of this 1, Heard before, but not at all familiar + not very familiar 2, Neither familiar nor unfamiliar + skipped + not asked 3, Somewhat familiar + very familiar 4*
Q8 Identify the single most environmental problem	*None of these or + don't know 1, Skipped + not asked 2, toxic waste + endangered species + acid rain + smog + water pollution + overpopulation 3, Ozone depletion + climate change + green spaces + destruction of ecosystems and resource depletion scored 4*
Q9, climate change is caused by a hole in the earth's atmosphere → False	*True 2, False 1*
Q10, every time we use coal or oil or gas, we contribute to the greenhouse effect→ *True*	*True 2, False 1*
Q*11,* is oxygen is the main component of the smoke emitted from a chimney or exhaust pipe→ *False*	*True 2, False 1*
Q12, coal is produced from dead plants→ *True*	*True 2, False 1*
Q13, which, if any, of the following activities, have a "significant" impact on levels of carbon dioxide in the atmosphere	*Yes increase carbon dioxide by driving cars, home heating, coal-burning power plants, factories (e.g., steel mills) 4* *Yes increase carbon dioxide by biomass power plants (burning wood or agricultural residues) and from breathing 3* *Skipped + not asked option 2* *Yes increase carbon dioxide by nuclear power plants + wind turbines + planting trees + oceans 1*
Q14, if you were responsible for designing a plan to address climate change, which, if any, of the following technologies, would you use to address climate change	*Definitely use 5, Probably using 4, Neutral + don't know 3, Probably not using 2, and Definitely not using 1*
Q15, Relative to others in the UK, how would you describe your likelihood to save energy at home	*Much less likely + Less likely 1, About as likely 2,* *More likely + Much more likely 3*
Q16, how often, if ever, do you reduce your thermostat or set your heating system, specifically to save money on your home energy bill (or indirectly to attain energy efficiency or saving energy consumption).	*Never + Rarely 1, Not applicable + don't know 2,* *Fairly often + very often 3*
Q17, what is the source of heat in your home	*Gas central heating/gas boiler + Heat pumps (ground source) + Oil heating + LPG central heating 1, Storage heaters + Electric resistance heating + Other and Don't know 2, Immersion heaters + District heating + Electric central heating + Biomass heating system + Solar hot water heating 3*

Carbon capture and storage (CCS), Liquid petroleum gas (LPG), Negative emission technologies (NETs), Question (Q).

$$\text{Prob}\ (\textit{Willingness to save energy} / \textit{Performance\_heat set} / \textit{Performance\_heat source}\ i = j) = \frac{e^{\beta_j\ \delta_i}}{\sum_{k=1}^{j} e^{\beta_j\ \delta_i}}$$

Here, $j = 1, \ldots 3$ describe the three classes for Willingness to save energy (Less willing, Willing and Very willing) and Performance_heat set (No energy saver, Information unknown and Energy Saver), Performance_heat source (Nonrenewable user, Source unknown user and Renewable user). The above equation represents a set of different probabilities of a person (i's) choice from the j classes to take a set of decision with δ_i characteristics, where the total probability is 1.

Table 3
Representation of MNLR variables.

Q	Variable	Definitions	Consequence	Coding
5–14	Knowledge Index	0-1→ Poor knowledge index (PKI)	Poor knowledge	1
		1.01–1.5→ Good knowledge index (GKI)	Good knowledge	2
		>1.5 → Very good knowledge index (VGKI)	Very good knowledge	3
15	Willingness to save energy	Much less likely + Less likely	Less willing	1
		About as likely	Willing	2
		More likely + Much more likely	Very willing	3
16	Performance_heat set	Never + Rarely	No energy saver	1
		Not applicable + don't know	Information unknown	2
		Fairly often + very often.	Energy Saver	3
17	Performance_heat source	Gas central heating/ gas boiler, Heat pumps (ground source), Oil heating, LPG central heating.	Nonrenewable user	1
		Storage heaters, Electric resistance heating, Other and Don't know	Source unknown user	2
		Immersion heaters, District heating, Electric central heating, Biomass heating system, Solar hot water heating	Renewable user	3

Good knowledge index (GKI), Multinomial logistic regression (MNLR), Poor knowledge index (PKI), Question (Q), Very good knowledge index (VGKI).

2.3. *Questionnaire reliability test*

Before continuing the final analysis, this study sought to identify the correlations across question. Hence, a reliability test is executed to check the consistency of all the questions (except for the respondents' basic information) by using Cronbach's alpha. The reliability test result or Cronbach's alpha of all the questions is 0.70, which implies that the questions in the questionnaire are consistent with investigating the aim of the corresponding study [38].

3. Results

3.1. *Knowledge about climate change and carbon technology*

3.1.1. *Regional distribution of knowledge index*

The survey results revealed that 13% of respondents have poor (i.e., 0–1) knowledge, 80% have good (1.01–1.5) knowledge and 7% have very good (i.e., >1.5) knowledge about climate change and CO_2 emissions reductions (Fig. 2a).

The regional study revealed that the majority (i.e., 74%–80%) of respondents in all regions have good knowledge about the related concepts of climate change and carbon issues. Of all the regions, outliers were the South West region where 84% of respondents had good knowledge and the South East, Yorkshire and the Humber, and West Midlands where around 15%–19% of respondents had poor knowledge about climate issues.

For the very best informed, around 9%–10% respondents in the North East, East Midlands and London had very good knowledge concerning climate issues, whereas in the West Midlands, only 2% of respondents had very good knowledge, which was the lowest of all regions (Fig. 2b), although the difference was not found to be significant according to Pearson's chi-square test.

3.1.2. *Knowledge index vs. social grade*

Knowledge index and social grade have a close relationship as knowledge is backed up by experience, education status, social status. This is because social status provides better opportunities for people to have a higher education status. In other words, an educated person can reach the highest social level. Thus, that person also can enrich their knowledge level.

The study revealed that among the total respondents around 33%, 46% and 21% belong to the social grade levels A and B, C1 and C2, and D and E respectively. The majority of the C1 and C2 social grade respondents have good knowledge. Therefore, among the 46%, 37% and 3% of the C1 and C2 respondents have good and very good knowledge than other social grade respondents.

It is noteworthy that about 26% of A and B social status respondents have good and 3% have very good knowledge about climate and carbon management issues (Fig. 2c). The knowledge index versus social grade study is significant according to Pearson's chi-square test ($X^2 = 36.97$, df. = 10, $p < 0.00$).

3.1.3. *Knowledge index vs. educational qualification*

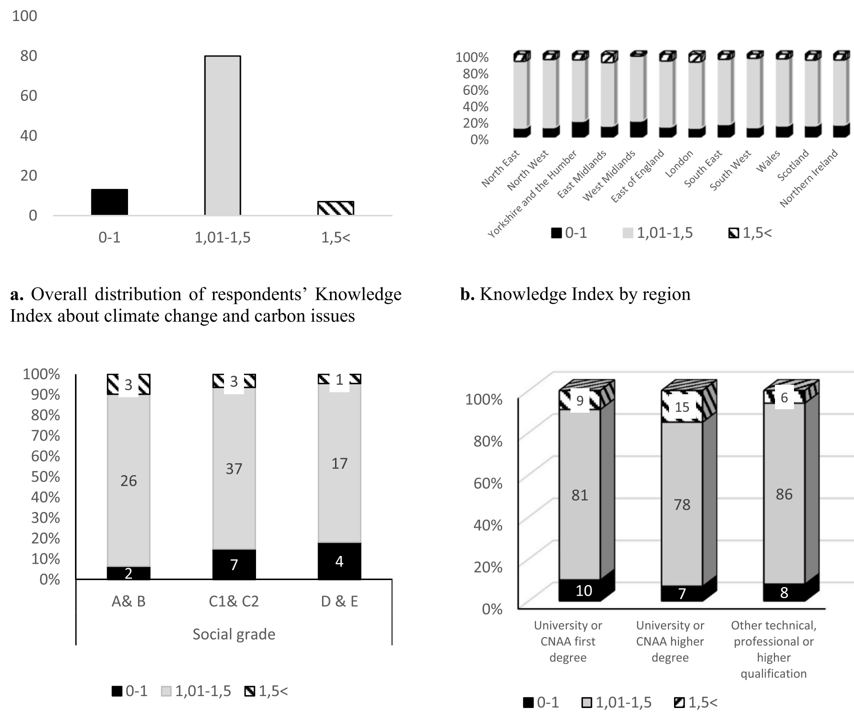
Among all the categories of educational types, this section focused on those with University or CNAA first degree (e.g., BA, B.Sc, B. Ed), University (22%) or CNAA higher degree (e.g., M. Sc, Ph. D) (about 8%) and other technical, professional or higher qualification respondents (about 12) among the other categories. Among these categories, about 80–85% respondents have good knowledge about carbon issues. Remarkably, among these three educational qualification types, University or CNAA first degree and University or CNAA higher degree respondents have very good knowledge compared to other technical, professional or higher qualification respondents. Although this figure is not high enough, it can be said that the University or CNAA first degree and University or CNAA higher degree respondents have better knowledge than other technical, professional or higher qualification respondents about climate change (Fig. 2d). The knowledge index versus education study is significant according to Pearson's chi-square test ($X^2 = 60.68$, df. = 4, $p < 0.00$).

3.2. *Knowledge vs. willingness to different technology comparison*

In the willingness section, the proposed technology that respondents will design to address climate change were bioenergy (biomass), afforestation and reforestation, CCS with gas power, CCS with bioenergy, CCS coal, nuclear, solar and wind. The study found that respondent want to use (definitely + probably) the bioenergy (biomass; 59%), afforestation and reforestation (87%), CCS with gas power (32%), CCS with bioenergy (36%), CCS coal (26%), nuclear (36%), solar (88%) and wind (85%) energy for their future energy sources.

The answered variables were evaluated by a scatter plot matrix to estimate the correlation between the variables. The scatter plot matrix was utilised to investigate how much one variable is affected by another variable in response to the respondents' answering selection. The relationship of one variable with others are represented as a scatter plot. The trend data are moving from left to right for the x-axis value and the y-axis values are moving from down to up (Fig. 3). The x-axis variable combines with the y-axis variable to create a pair. The black diagonal line represents a total fit line. So, when the correlation value of each pair will be 1, it will fit along the diagonal black line and represent a high degree positive correlation [39]. In Fig. 3a, the histogram that diagonally represented the relation between each variable to pair with own, like the x-axis variable with the y-axis variable.

The study found a positive correlation between the variables in every situation, except with nuclear energy where nuclear versus bioenergy had an absolute value of $r = -0.013$, nuclear versus solar had an



a. Overall distribution of respondents' Knowledge Index about climate change and carbon issues

b. Knowledge Index by region

c. Knowledge Index by social grade

d. Knowledge Index versus educational qualification

Fig. 2. a. Overall distribution of respondents' Knowledge Index about climate change and carbon issues; b. Knowledge Index by region; c. Knowledge Index by social grade; d. Knowledge Index versus educational qualification.

absolute value of $r = -0.007$ and nuclear versus wind had an absolute value of $r = -0.05$.

The study found that CCS bio versus CCS gas had a strong correlation (absolute value $r = 0.67$), as respondents selected both variables simultaneously for their future energy design. The relationship between the corresponding variables of Fig. 3a is represented clearly in Fig. 3b by using a jitter plot. However, the variables correlation points are tighter and falling along the total fit line. The total fit line also starts close to the area of the 0.0 axis. Interestingly, this correlation is very strong for the good and very good knowledge index respondents, which is quite different for the poor knowledge index respondents. The poor knowledge index respondents are intact with CCS gas and indifferent to CCS bio and vice versa.

Furthermore, the strong correlation (absolute value $r = 0.64$) between CCS coal versus CCS gas is represented clearly in Fig. 3c. In the figure, the very good knowledge index respondents chose the mostly neutral or don't know option in the case of using both variable materials as their future energy consumption design, whereas the good knowledge index respondents maintained a strong positive correlation between the variables. In the case of CCS bio versus CCS coal, the study also found a positive strong correlation (absolute value $r = 0.64$). The positive correlation is built strongly by the good and very good knowledge respondents.

Wind versus solar (0.65) and CCS coal versus CCS bio also represented a high positive correlation. Interestingly, in the solar versus wind correlation, the high knowledge index respondents had the tendency to definitely use both energy options (Fig. 3d). Furthermore, for CCS coal versus CCS bio, the study found that the highest knowledge index demonstrated indecision when selecting the energy sources and prioritised the neutral or probably use options (Fig. 3e).

The study found a moderate correlation between wind versus afforestation (absolute value of $r = 0.56$) and solar versus afforestation (absolute values of $r = 0.55$) (Fig. 3f and g). Good and very good knowledge index respondents had a tendency to select the answer probably and definitely use both the technologies.

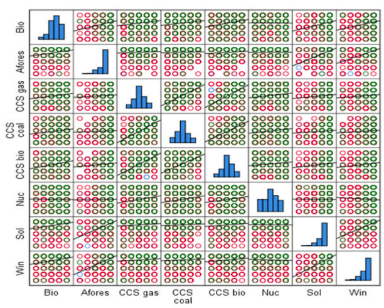
For bioenergy versus any technologies except nuclear, the study found a consistent positive though weak correlation. For nuclear versus all other technologies, there was either a slightly positive or negative correlation although generally the total fit line is quite flat (i.e., the slope is close to zero) (Fig. 3a). Overall, correlations were very weak between the variables (r varies between 0.03–0.21).

3.3. *Willingness vs. performance for energy saving*

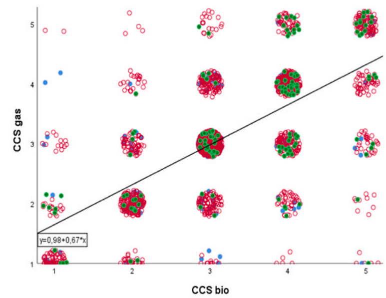
In the knowledge versus willingness comparison, it appears that very few respondents of the different knowledge indices are much and less likely to save energy than others (about 5%). In comparison, about 47% and 49% of respondents found about as likely to save energy as others and more and much more likely to save energy than others, respectively (Fig. 4a). Therefore, in response to the question, how often does the respondent set their heating system, about 14% responded never, 27% rarely, 11% don't know or were unwilling to answer the question, 32% fairly often and 15% very often set their heating system to save energy. Interestingly, around 3% of respondents who have very good knowledge about climate change and carbon issues never or rarely set their heating system. However, among the moderate knowledge index around 40% of respondents fairly often or very often set their heating system (Fig. 4b).

The comparative analysis between Q 15 and Q 16 represents that, in total, the majority (more than 80%) of respondents are found as about as likely to save energy as others, more and much more likely to save energy than others. It is important to say only half of them (about 47%) set their heating system. About 15%, 13% and 9% of respondents, who respond as about as likely, more likely or much more likely to save than others, never set their heating system to save energy (Fig. 4c). Furthermore, only 31%, 25% and 17% responded as likely, more likely and much more likely to save than others, and rarely set their heating system, respectively.

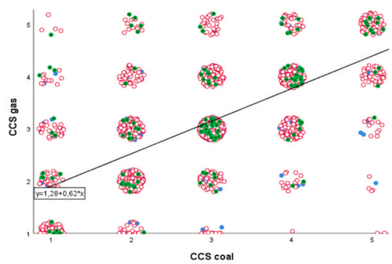
It is highly significant to notice that in the case of setting heating



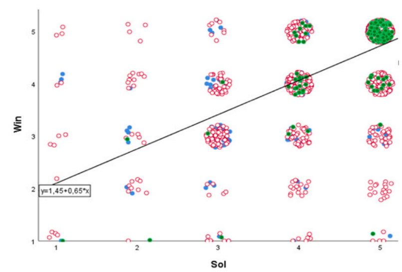
a. Scatterplot matrix of Willingness variables



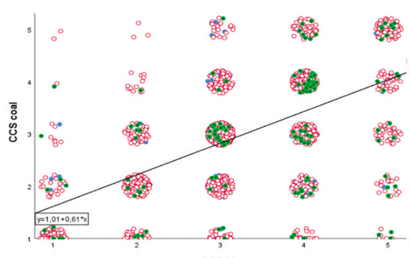
b. CCS gas by CCS bio with Knowledge Index



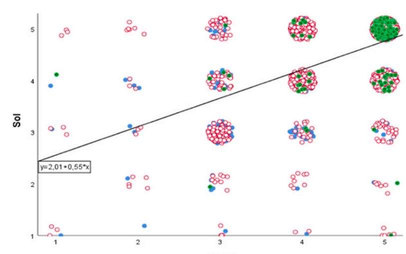
c. CCS gas by CCS coal with Knowledge Index



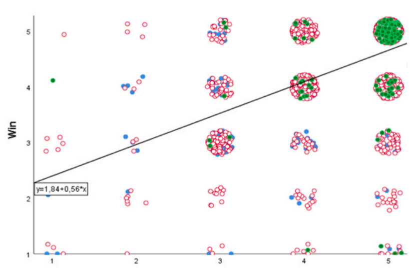
d. Wind (Win) by Solar (Sol) with Knowledge Index



e. CCS coal by CCS bio with Knowledge Index



f. Solar (Sol) by Aforestation (Afores)with Knowledge Index



g. Wind (Win) by Aforestation (Afores) with Knowledge index

CCS gas- Carbon capture and storage with gas power

CCS coal- Carbon capture and storage with coal power

CCS bio- Carbon capture and storage with bioenergy

Knowledge Index:

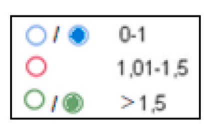
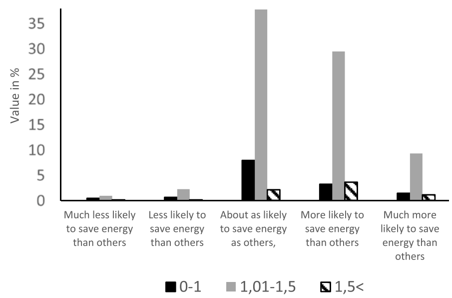


Fig. 3. Willingness to reduce carbon emissions based on Knowledge Index.

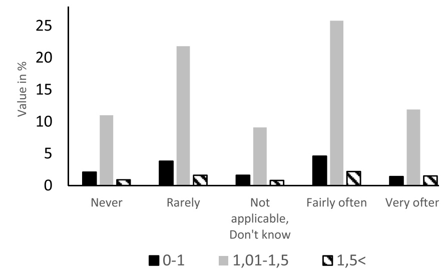
systems, the study found a good relation between the fairly often and very often scale of Q 16 and the scale of as likely to save as others, more and much more than others of Q 15. In Q 15, about 31%, 36% and 30% of respondents are found as likely to save as others, more and much more than others, fairly often set the heating system, respectively. Furthermore, in Q 16, about 10%, 15% and 36% of respondents are found as likely to save as others, more and much more save than others very often set the heating system, respectively.

3.4. *Knowledge, willingness and performance: a multinomial prediction*

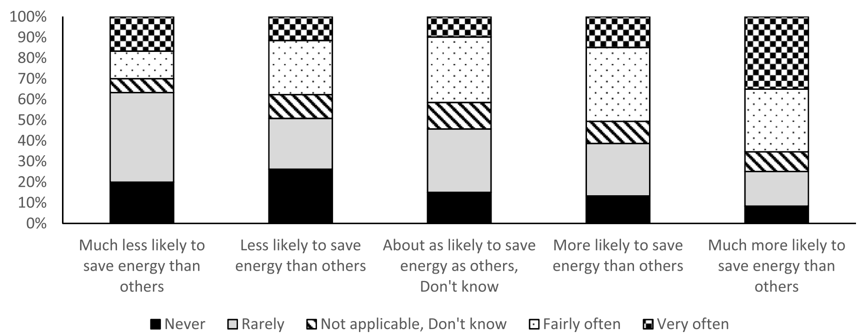
Respondents' performance are also estimated based on the heating sources (Q17) used for household heating. Most respondents use either a gas boiler and gas central heating, an oil heating system or an electric central heating system (around 75%, 6% and 5%, respectively). A very small percentage of respondents (less than 1%) utilise a biomass heating system. Furthermore, about 5% of good knowledge respondents are utilising an oil heating system. Note that about 7% of poor, 4% of good



a. Willingness to save energy versus Knowledge Index



b. Performance: setting heating system



c. Willingness to save energy versus performance based on heating source

Fig. 4. a. Respondents' willingness to save energy versus Knowledge Index (above left); b. Performance: setting heating system versus Knowledge Index (above right); c. Willingness to save energy versus performance based on heating source (below).

and even 5% of very good respondents (as defined by the knowledge index) do not know the fuel used in their home heating system.

The MNLR study of knowledge vs willingness studies found the effect of the odds of a 1 unit increase in GKI and VGKI level is exp (0.42) or 1.52 and exp (0.33) or 1.40 for willing to save carbon emission. Meaning incrementing KI increases the odds by 52% and 40%, respectively. Further, the effect of the odds of 1 unit increases in GKI and VGKI level is exp (0.98) or 2.66 and exp (1.67) or 5.31 for those very willing to reduce carbon emission, which meaning incrementing KI increases the odds by 33% and 6%, respectively.

In the performance (heat setting) vs knowledge studies, the effect of the odds of a 1 unit decreases in GKI and increase VGKI level is exp (−0.01) or 0.99 and exp (0.12) or 1.13 respectively for Perf_ heat set_unknown. Meaning incrementing KI decreases and increases the odds by 1% and 13%, respectively. The effect of the odds of 1 unit increases in GKI and VGKI level is exp (0.13) or 1.14 and exp (0.35) or 1.42 for Perf_heat set to reduce carbon emission. It implies that incrementing KI increases the odds by 14% and 35%, respectively.

In the performance (heat source) vs knowledge studies, the effect of the odds of a 1 unit increases in GKI and VGKI level is exp (−0.17) or 0.84 and exp (−0.33) or 0.77 for performing to Perf_ heat source_unknown. It implies that incrementing KI decreases the odds by 16% and 33%. The effect of the odds of 1 unit increases in GKI and VGKI level is exp (−0.18) or 0.83 and exp (−0.07) or 0.93 for Perf_ heat source to reduce CO_2 emissions. This implies that incrementing KI decreases the odds by 17% and 7%, respectively.

Although the pseudo-R-squared or McFadden r^2 is small, even values in the range of 0.20 to 0.40 would indicate an excellent fit. The two

Table 4
Results of MNLR study.

Variable Co-efficients	Willingness to save energy_willing (P value)	Willingness to save energy_very willing (P value)	Perf_ heat set_unknown (P value)	Perf_ heat set (P value)	Perf_heat source_unknown (P value)	Perf_heat source_RE (P value)
Intercept	**2.08 (0)****	**1.54 (0)****	**−1.27 (0.0)****	**0.02 (0.0)****	**−2.01 (0) ****	**−2.27 (0)****
GKI	0.42 (0.22)	**0.98 (0)****	**−0.01 (0.04)***	0.13 (1.30)	−0.17 (1.18)	−0.18 (1.14)
VGKI	0.33 (0.88)	**1.67 (0)****	0.12 (0.56)	0.35 (0.22)	−0.33 (1.30)	−0.07 (0.32)
RD	3541.46		4138.32		2434.40	
AIC	3553.46		4150.32		2446.40	
Initial value	2347.74		1481.26		2347.74	
Final value	1770.40		1476.86		1217.20	
McFadden r^2	0.013		0.007		0.007	
ARE	48%		17%		16%	

Akaike Information Criteria (AIC), Accuracy rate of error (ARE), Poor knowledge index (PKI), Good knowledge index (GKI), Very good knowledge index (VGKI), Residual Deviance (RD), Renewable energy (RE).

tailed z-test provides the p-value. The result that is less than 0.5, this number is doubled and if the result is more than 0.5, then deduct the result from 1 and doubled it to get the p-value [40]. Thus, in the two-tailed test if the final *P*-value is less than 5% ($p < 0.05$) means the result is significant (Table 4).

4. Discussions and conclusions

Many people of the world are concerned about climate change and have knowledge about carbon emissions. According to special Eurobarometer 435 [41], the top three countries where people think that climate change is the most serious problem that the world is suffering from now are Denmark, Sweden and Finland. The people of the UK consider climate change to be the one of the top three most serious problem [42]. Delzendeh et al. [43] signifies that climate change might be the biggest environmental challenge and risk for the future. However, it has not happened in a single day or a single year. The climate has been deteriorating for several decades and human activities are mostly responsible. Ten years ago, a study revealed that globally, households were consuming 29% of energy and releasing 21% of global CO_2 [44] and the rest of the major sectors like transport and manufacturing were indirectly influenced by human consumption habits and behavioural trends.

In the UK, household energy consumption in 2010 was 10% higher than in 1970 [45]. Energy consumption in 2018 in the UK increased to 1.1% more than in 2013; the major share supplying source was gas and the major demanding sector was domestic households [45]. Thus, UK households are responsible for emitting about 14% of the total GHGs and gas boilers are the main source [46]. Another study indicated that in 2019 direct GHG emissions from the households were about 87 Mt CO_2e, and that was mainly from heating sources [30]. Thus, reducing carbon emission in heating is a significant challenge for the UK to attain a zero-carbon target. Although this household carbon emissions ratio is still less than some other sectors, let us not forget that the demand of this sector is getting higher and higher every day.

The studies by Girod [47] and Nissinen et al. [48] indicated that human knowledge motivated their willingness to reduce consumption and that this can create an enormous opportunity to reduce GHG emissions. Various studies (e.g. Refs. [49–51]) in the field of environmental studies, people's knowledge has a noteworthy association with their behaviour. A study by Guo et al. [52] indicated that human behavioural studies offer a direction to develop a genuine policy backed by actual evidence. Thus, human behaviour is identified as one of the most substantial factors in domestic energy consumption [53]. Changing the behavioural pattern can help save the operational expenditure £0.4 billion/year by 2050 [30]. Therefore, the survey study concerning climate and carbon issues for households is significant.

Hence, this study investigates knowledge and specifically the knowledge-willingness, knowledge-performance and willingness-performance gaps over reducing carbon emissions and future-oriented technologies in the UK. This study found that in total and from the regional perspective about 80% of respondents had at least good knowledge about climate change and carbon emissions reduction issues. The social grade study found that about 40% of C1 and C2 social grade respondents have good and very good knowledge about climate issues compared to others. The educational qualification versus knowledge index study found that respondents with a University first (or higher) degree have better knowledge about climate change than respondents with other technical, professional or higher qualifications. The findings of our study are supported by the study by Miller et al. [8], that the better educated have greater knowledge concerning upcoming potential technologies.

The strongest positive correlation for future energy preferences was between CCS bio and CCS gas, CCS bio and CCS coal and CCS coal and CCS gas. It demonstrates that people in the UK are very much aware of their gas and coal energy sources and want to stick with their current primary energy sources if CCS technology might be applied.

In the case of using bioenergy, the study found respondents are more willing to use it than CCS bioenergy. This finding also supported by the study by Evans [54], as 80% of respondents in the UK believe that bioenergy is making a major contribution in the UK energy mix. This is because people's "environmental beliefs" might have a positive influence over their WTP for low-carbon products [55]. Thus, in our intuition, it is quite normal that in this current era due to climate change people are considering bioenergy, and thus it gets selected by the respondents for their future energy plan. The reason behind accepting bioenergy more than the CCS of bioenergy might be that many people still do not have enough knowledge about CCS bioenergy. Many people still do not know that bioenergy (especially woody biomass) is not a completely carbon neutral energy [56]. The same explanation is applicable for respondents retaining wind and solar in their energy plan.

However, in the correlation analysis, the study found that although bioenergy has a poor correlation with other technologies, CCS bioenergy is representing something different. In the case of bioenergy, respondents have much less intention to switch to others which is quite the opposite in the case of CCS bioenergy versus CCS coal and CCS gas. Thus, the CCS coal or CCS gas user can move to CCS bioenergy or vice versa.

The positive correlation between wind versus solar reveals that respondents made similar selections for both these technologies as the majority of respondents want to use both these technologies for their future energy plan in same way. The available facilities and reasonable prices allow for respondents to switch from one to the other without any hesitation. These positive correlations, between different future technologies, reveal that there is actually only a small gap between the respondent's knowledge versus their willingness. This gap might be completely removed in the near future by extending the socio-demographic characteristics; this finding is sustenance by the special Eurobarometer 435 study [42], which revealed that 23% of UK respondents believe it is their collective responsibility to mitigate climate change.

Thus, this small contributing figure might be more significant when their collective actions influence other respondents' knowledge level, growing trust and willingness to utilise future carbon capturing and renewable technologies [8]. Further, these strong positive correlations between future technologies to address climate change send a message to energy suppliers, regulators and policymakers that people can switch from one energy source to another and make similar selections for both types of energy. In the willingness versus performance study, there is a considerable gap. About 96% of respondents think of themselves about as or more or much more likely energy savers; whereas, about 52% of them are never or rarely set their heating system to save energy.

The study also found that although respondents are highly willing to save energy, more than half of them rarely regulate their heating system to save energy. There is also an enormous gap in the knowledge versus performance comparison; despite selecting bioenergy, solar, wind or nuclear, around 75% of respondents of the 66% that have good and very good knowledge are using gas boilers and gas central heating.

Therefore, the findings of this study raise two questions. First, despite having good knowledge and a willingness to utilise renewable energy to reduce carbon emissions, why do respondents continue to use gas energy for their heating system? Although many respondents prefer to include solar and wind in their future energy plans, why do respondents currently use gas instead of wind or solar for their heating sources? The wide availability of gas and the low cost might be a reason, but in that case, it might seem difficult to reconcile the preference for renewables in their future energy plans. Another consideration is that in the UK gas is now mostly dependent on imports from other countries–75% of gas is imported from Norway, 10% from Belgium and the Netherlands and 15% is imported from Qatar as Liquefied Natural Gas (LNG) [57].

The MNLR study has been done where the ultimate aim was to identify the knowledge, willingness and performance relationship. As like study of James et al. [58] performance is considered as DV; and as of performance willingness is also considered as DV and knowledge as IV.

The MNLR study reveals that the study of GKI and VGKI vs very willingness to save energy (incrementing KI increases the odds by 33% and 6%) and GKI vs unknown of heat setting performance (incrementing KI decreases the odds by 1%) are significant ($p < 0.05$). Whether the study found knowledge vs heating sources performance has, in fact, an insignificant relation.

Though this worsens import and consumption facts, it is significant to mention that the UK's Committee on Climate Change (CCC) has already decided to ban gas boilers and hobs in new homes after 2025. The CCC has suggested that new homeowners connect with the low-carbon energy grid [59–61].

It is hopeful that during 1990–2009, 24% (1.4%/yearly average rate) of energy efficiency was attained in the domestic energy consumption sector, and that was by following the efficient building construction principle, smart heating machinery and electrical appliances [62]. Further, the application of commercially available smart technology, following smart building principles, and developing a smart energy system that is available, efficient and provides low costs could be better options to control and attain heating and energy efficiency [63,64].

Houseowner's less interest in investing in unfamiliar technology, installation costs for the new smart technologies, delay [29] and uncertainty in the period of technological transition are key barriers to expanding Energy-efficient technologies. The UK government and stakeholders concerning energy issues, especially some private organisations, are now trying to empower household representatives to decide on better Energy for their houses.

The CCC also estimated that low carbon heating installation will cost £4800 and £26,300, for new and existing homes respectively [46]. Therefore, as a consequence, electric heat pumps that have been already installed are now demonstrating energy efficiency. Currently, among the UK's 29 million, less than a quarter of a million households only use heat pumps [65].

The UK energy market has been seen increased penetration of renewables; in recent years, the capacity has tripled, while fossil fuel has dropped by one-third [66]. According to a study by National Grid [67], in the first half of 2019, clean energy (wind and solar) plus nuclear (48%) surpassed fossil energy (47% for coal and gas) in electricity generation for the first time. However, continued development of renewable energy will require not just technical and economic progress but also changing individual and social practices [68]. For example, Hansen [69] describes how 'sticky practices' such as that maintaining existing levels of home heat consumption will be difficult to overcome.

Thus, the policymaker and researcher should create an intensive plan to expand the renewables market and penetrate into the UK gas market, for example, by applying price control or providing promotional benefits in favour of renewables. However, price controlling has a limited scope as gas prices are decided by different stakeholders of the global markets [70]. Nevertheless, promotional and awarding activities in the renewable market can encourage new customers. Thus, social studies are substantial as it redefines society's energy demand highly influence on the country's energy policy development and implementation [71].

The second question raised by the study is, despite having good knowledge and willingness to reduce emissions, why do so few of the respondents do relatively simple things like set their heating system to save energy? One reason may be that the way people receive knowledge and process, and the resulting actions may lead to the perception that they have a lack of urgency to mitigate climate change.

This small indifference might also be removed by providing an award system for the energy saver, fixing a household consumption quota or setting an individual carbon footprint limit. People's consciousness can be heightened also by creating the proper environment (i.e., campaigning, training, etc.). The government and industry can jointly encourage green consumption [55]. In this case, a perception study can be conducted in the future to understand people's perceptions concerning the saving and usage of energy, which might help the energy market designer develop their policies [72]. If the costs side is possible to ignore or technically become updated, the CCS of gas initiatives could be one of the best solutions for the UK, as the gas market is quite large. Thus, potential renewable consumers can also consider it in advance and contribute to the improvement of global climate change.

Credit author statement

Tahamina Khanam (TK): Conceptualization, Methodology, Data curation, Validation, Visualisation, Writing – original draft. **David Reiner (DR):** Investigation, Resources, Writing– review & editing-and Supervising.

Declaration of competing interest

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

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References

[1] Summary for Policymakers. Global warming of 1.5°C. In: Masson-Delmotte V, Zhai P, Pörtner H-O, Roberts D, Skea J, Shukla PR, editors. An Intergovernmental Panel on Climate Change Special Report on the impacts of global warming of 1.5°C. IPCC; 2018.
[2] Höhne N, Gidden MJ, den Elzen M, Hans F, Fyson C, Geiges A, et al. Wave of net zero emission targets opens window to meeting the Paris Agreement11(10). Nature Clim Change; 2021. p. 820–2. https://ca1-eci.edcdn.com/briefings-documents/Negative-emissions-PDF-compressed.pdf?mtime=20190529123951. [Accessed 23 August 2020]. 2018.
[3] Ivanova D, Stadler K, Steen-Olsen K, Wood R, Vita G, Tukker A, et al. Environmental impact assessment of household consumption: environmental impact assessment of household consumption. J Ind Ecol 2016;20:526–36.
[4] Hertwich EG, Peters GP. Carbon footprint of nations: a global trade-linked analysis. Environ Sci Technol 2009;43:6414–20.
[5] Fajardy M, Mac Dowell N. Can BECCS deliver sustainable and resource efficient negative emissions? Energy Environ. Sci. 2017;10(6):1389–426.
[6] Metz B, Davidson O, Coninck de H, Meyer MLL. IPCC Special Report on Carbon Dioxide Capture and Storage. 2005. https://www.ipcc.ch/site/assets/uploads/2018/03/srccs_wholereport-1.pdf. [Accessed 7 July 2020].
[7] Bolisani E, Bratianu C. Knowledge strategy planning: an integrated approach to manage uncertainty, turbulence, and dynamics. J Knowl Manag 2017;21(2): 233–53. https://doi.org/10.1108/JKM-02-2016-0071. 2017.
[8] Miller E, Bell LM, Buys L. Public understanding of carbon sequestration in Australia: socio-demographic predictors of knowledge, engagement and trust. Intl. J. Emerg Technol. Soc. 2007;5(1):15–33.
[9] Rahman A, Khanam T, Pelkonen P. People's knowledge, perceptions, and attitudes towards stump harvesting for bioenergy production in Finland. Renew Sustain Energy Rev 2017;70:107–16. https://doi.org/10.1016/j.rser.2016.11.228.
[10] Letwin O, Barker G, Stunell AOBE. Behaviour Change and Energy Use: Behavioural Insights Team Paper. UK: GOV; 2011. https://www.gov.uk/government/publications/behaviour-change-and-energy-use-behavioural-insights-team-paper. [Accessed 9 August 2021].

[11] Frederiks ER, Stenner K, Hobman EV. Household energy use: applying behavioural economics to understand consumer decision-making and behavior. Renew Sustain Energy Rev 2015;41:1385–94. https://doi.org/10.1016/j.rser.2014.09.026.
[12] Eleazar PJM, Demafelis RB, Matanguihan AED, Tongko-Magadia BD, Gatdula KM, Predo CD. Knowledge, attitude, perception and willingness-to-pay survey for imposing carbon tax in the Philippines. Philippine J crop sci 2017;42(3):1–10.
[13] Gil JM, Soler F. Knowledge and willingness to pay for organic food in Spain: evidence from experimental auctions. Acta Agr Scand, Sec. C — Food Econ. 2007;3 (3–4):109-24.
[14] Huang CHL. Consumer preferences and attitudes towards organically grown produce. Eur Rev Agric Econ 1996;23(3):331–42.
[15] Sanjuán AI, Sánchez M, Gil JM, Gracia A, Soler F. Brakes to the organic market enlargement in Spain: consumers and retailers' attitudes and willingness to pay. Int J Consum Stud 2002;27(2):134–44.
[16] Schwirplies C, Dütschke E, Schleich J, Ziegler A. Consumers' willingness to offset their CO_2 emissions from traveling: a discrete choice analysis of framing and provider contributions. Working Paper, https://www.econstor.eu/bitstream/10419/157940/1/886287448.pdf. [Accessed 7 August 2021].
[17] Zhao Y, Wang C, Sun Y, Liu X. Factors influencing companies' willingness to pay for carbon emissions: emission trading schemes in China, 2018. Energy Econ 2018; 75:357-67.
[18] Department for Business, energy and industrial strategy. 2018 UK Greenhouse Gas Emissions, Final figures. 2020. https://assets.publishing.service.gov.uk/government/uploads/system/uploads/attachment_data/file/862887/2018_Final_greenhouse_gas_emissions_statistical_release.pdf. [Accessed 7 August 2021].
[19] Department for Business, energy and industrial strategy. 2018 UK Greenhouse gas Emissions, provisional figures. In: Statistical release: national statistics; 2019. https://assets.publishing.service.gov.uk/government/uploads/system/uploads/attachment_data/file/790626/2018-provisional-emissions-statistics-report.pdf. [Accessed 17 December 2020].
[20] Department for environment food and rural affairs. https://assets.publishing.service.gov.uk/government/uploads/system/uploads/attachment_data/file/794557/Consumption_emissions_April19.pdf. [Accessed 2 August 2021].
[21] Department for Business, energy and industrial strategy. UK becomes first major economy to pass net zero emissions law. https://www.gov.uk/government/news/uk-becomes-first-major-economy-to-pass-net-zero-emissions-law. [Accessed 11 July 2021].
[22] Marbuah G, Gren I-M, Tirkaso WT. Social capital, economic development and carbon emissions: empirical evidence from counties in Sweden. Renew Sustain Energy Rev 2021;152:111691.
[23] Sovacool BK, Cabeza LF, Pisello AL, Colladon AF, Larijani HM, Dawoud B, Martiskainen M. Decarbonizing household heating: reviewing demographics, geography and low-carbon practices and preferences in five European countries. Renew Sustain Energy Rev 2021;139:110703.
[24] The Economics of Climate Change: The Stern Review - Nicholas Stern. Nicholas herbert stern. Great Britain: Treasury - google books; 2006. https://webarchive.nationalarchives.gov.uk/ukgwa/20100407172811/https:/www.hm-treasury.gov.uk/stern_review_report.htm. [Accessed 9 December 2021].
[25] Eu. Available at: energy consumption in households. https://ec.europa.eu/eurostat/statistics-explained/index.php?title=Energy_consumption_in_households; 2021.
[26] Special feature – Estimates of heat use in the Uk. Estimates of heat use in the United Kingdom in 2013. 2014. https://assets.publishing.service.gov.uk/government/uploads/system/uploads/attachment_data/file/386858/Estimates_of_heat_use.pdf.
[27] Aude. AUDE's higher education estates management report 2019. Available at. 2019. https://www.aude.ac.uk/news/publications/ems-report/. [Accessed 22 April 2020].
[28] Streimikiene D, Volochovic A. The impact of household behavioral changes on GHG emission reduction in Lithuania. Renew Sustain Energy Rev 2011;15: 4118–24.
[29] Energy saving trust. The future of heating in the UK: heat pumps or hydrogen?. https://energysavingtrust.org.uk/the-future-of-heating-in-the-uk-heat-pumps-or-hydrogen/; 2021.
[30] Climate change committee 2020. The Sixth Carbon Budget Buildings. Available at: https://www.theccc.org.uk/wp-content/uploads/2020/12/Sector-summary-Buildings.pdf.
[31] Brown TW, Bischof-Niemz T, Blok K, Breyer C, Lund H, Mathiesen BV. Response to 'Burden of proof: a comprehensive review of the feasibility of 100% renewable-electricity systems'. Renew Sustain Energy Rev 2018;92:834–47.
[32] National Readership Survey. Social Grade. NRS; 2016. https://www.nrs.co.uk/nrs-print/lifestyle-and-classification-data/social-grade/. [Accessed 7 January 2022].
[33] Nasa. Is the ozone hole causing climate change? – climate change: vital signs of the planet. https://climate.nasa.gov/faq/15/is-the-ozone-hole-causing-climate-change/. [Accessed 17 August 2021].
[34] Munton AG, Wright AJ, Mallaburn PS, Boait PJ. How heating controls affect domestic energy demand. London: A Rapid Evidence Assessment; 2014.
[35] Decc. Smarter heating controls research program. London, https://assets.publishing.service.gov.uk/government/uploads/system/uploads/attachment_data/file/254877/smarter_heating_controls_research_programme_overview.pdf; 2012.
[36] R Core Team. R: A language and environment for statistical computing. Vienna, Austria: R Foundation for Statistical Computing; 2020. . [Accessed 5 May 2020].
[37] World Bank Institute. Measuring Knowledge in the World's Economies. 2009. http://web.worldbank.org/archive/website01030/WEB/IMAGES/KAM_V4.PDF. [Accessed 1 August 2020].
[38] Nunnally JC. Psychometric Theory. second ed. New York: McGraw-Hill; 1978.
[39] Freeman J, Young T. Correlation coefficient: Association between two continuous variables. 2009. https://www.sheffield.ac.uk/polopoly_fs/1.43991!/file/Tutorial-14-correlation.pdf. [Accessed 18 May 2021].
[40] Ucla. Statistical consulting group. https://stats.idre.ucla.edu/other/mult-pkg/faq/general/faq-what-are-the-differences-between-one-tailed-and-two-tailed-tests/. [Accessed 18 May 2021].
[41] European Commission. Climate change. Special Eurobarometer 435; 2015. https://ec.europa.eu/clima/sites/clima/files/support/docs/gb_climate_en.pdf. [Accessed 7 June 2020].
[42] European Commission. Climate change. Special Eurobarometer 435; 2015. https://ec.europa.eu/clima/sites/clima/files/support/docs/fi_climate_en.pdf. [Accessed 12 August 2021].
[43] Delzendeh E, Song W, Angela L, Ying Z. The impact of occupants' behaviours on building energy analysis: a research review. Renew Sustain Energy Rev 2017;80: 1061–71.
[44] International Energy Agency (IEA). Worldwide Trends in Energy Use and Efficiency. Paris, France: International Energy Agency; 2008. www.iea.org/publications/freepublications/publication/Indicators_2008.pdf. [Accessed 5 May 2020].
[45] Department for Business, Energy and Industrial Strategy (BEIS).. Energy Consumption in the UK (ECUK) 1970 to 2018. BEIS; 2019. https://assets.publishing.service.gov.uk/government/uploads/system/uploads/attachment_data/file/820843/Energy_Consumption_in_the_UK__ECUK__MASTER_COPY.pdf. [Accessed 7 August 2020].
[46] Taylor M. Low-carbon heating to replace gas in new UK homes after 2025. https://www.theguardian.com/environment/2019/mar/13/hammond-says-gas-heating-will-be-replaced-by-low-carbon-systems. [Accessed 18 May 2021].
[47] Girod B, Peter van Vuuren D, Hertwich EG. Global climate targets and future consumption level: an evaluation of the required GHG intensity. Environ Res Lett 2013;8:014016.
[48] Nissinen A, Heiskanen E, Perrels A, Berghall E, Liesimaa V, Mattinen M. Combinations of policy instruments to decrease the climate impacts of housing, passenger transport and food in Finland. J Clean Prod 2015;107:455–66.
[49] Borden R, Schettino A. Determinants of environmentally responsible behavior. J Environ Educ 1979;10(4):35–9.
[50] Arachchi JI, Managi S. Preferences for energy sustainability: Different effects of gender on knowledge and importance. Renew. Sustain. Energy Rev 2021;141: 110767.
[51] Bayard B, Jolly C. Environmental behavior structure and socio-economic conditions of hillside farmers: a multiple-group structural equation modeling approach. Ecol Econ 2007;62(3–4):433–40.
[52] Guo Z, Zhou K, Zhang C, Lu X, Chen W, Yang S. Residential electricity consumption behavior: influencing factors, related theories and intervention strategies. Renew Sustain Energy Rev 2018;81:399–412.
[53] D'Oca S, Hong T, Langevin J. The human dimensions of energy use in buildings: a review. Renew Sustain Energy Rev 2018;81:731–42.
[54] Evans H. The Public Perceptions of Bioenergy in the UK. The ETI; 2016. https://www.eti.co.uk/insights/public-perceptions-of-bioenergy-in-the-uk. [Accessed 3 March 2020].
[55] Zhong S, Chen J. How environmental beliefs affect consumer willingness to pay for the greenness premium of low-carbon agricultural products in China: theoretical model and survey-based evidence. Sustainability 2019;11(3):592.
[56] Khanam T, Matero J, Mola-Yudego B, Sikanen L, Rahman A. Assessing external factors on substitution of fossil fuel by biofuels: model perspective from the Nordic region. Mitig Adapt Strategies Glob Change 2016;21:445–60.
[57] Department for Business, energy and industrial strategy. UK Energy in brief. https://assets.publishing.service.gov.uk/government/uploads/system/uploads/attachment_data/file/728374/UK_Energy_in_Brief_2018.pdf. [Accessed 9 January 2021].
[58] March JG, Sutton RI. Crossroads—organizational performance as a dependent variable. Organ Sci 1997;8(6):698–706.
[59] Press Association. Ban gas boilers in new homes by 2025, says Committee on Climate Change. The Guardian; 2019 Feb 21. https://www.theguardian.com/environment/2019/feb/21/ban-new-gas-boilers-by-2025-says-committee-on-climate-change. [Accessed 15 May 2020].
[60] Thomas N, Hook L. Gas heating systems to be barred from new UK homes. https://www.ft.com/content/3f50601c-45a5-11e9-b168-96a37d002cd3. [Accessed 8 May 2021].
[61] McGrath M. Climate change: ban new gas boilers from 2025 to reach net-zero. https://www.bbc.com/news/science-environment-57149059; 2021.
[62] Eu. Energy efficiency and energy consumption in the household sector. https://www.eea.europa.eu/data-and-maps/indicators/energy-efficiency-and-energy-consumption-5/assessment; 2013.
[63] Sovacool BK, Del Rio DDF. Smart home technologies in Europe: a critical review of concepts, benefits, risks and policies. Renew Sustain Energy Rev 2020;120:109663.
[64] Kourgiozou V, Commin A, Dowson M, Rovas D, Mumovic D. Scalable pathways to net zero carbon in the UK higher education sector: a systematic review of smart energy systems in university campuses. Renew Sustain Energy Rev 2021;147: 111234.
[65] Mooney P. How can we convert the Private Rental Sector to heat pumps?. https://les.mitsubishielectric.co.uk/the-hub/how-can-we-convert-the-private-rental-sector-to-heat-pumps; 2021.
[66] Vaughan A. UK renewable energy capacity surpasses fossil fuels for first time. The Guardian; 2018 November 6. https://www.theguardian.com/environment/2018/nov/06/uk-renewable-energy-capacity-surpasses-fossil-fuels-for-first-time. [Accessed 18 May 2021].
[67] National Grid. Britain's clean energy system achieves historic milestone in 2019. 2019. http://media.nationalgrid.com/press-releases/uk-press-releases/corporate

-news/britain-s-clean-energy-system-achieves-historic-milestone-in-2019/. [Accessed 21 August 2020].

[68] Aslani A, Naaranoja M, Wong K-FV. Strategic analysis of diffusion of renewable energy in the Nordic countries. Renew Sustain Energy Rev 2013;22:497–505.

[69] Hansen AR. 'Sticky' energy practices: the impact of childhood and early adulthood experience on later energy consumption practices. Energy Res Social Sci 2018;46:125–39.

[70] The guardian. Letters: privatising energy is doomed to failure. 2019. https://www.theguardian.com/commentisfree/2019/aug/25/privatising-energy-doomed-to-failure-letters. [Accessed 1 June 2021].

[71] Spandagos C, Baark E, Ng TL, Yarime M. Social influence and economic intervention policies to save energy at home: critical questions for the new decade and evidence from air-condition use. Renew Sustain Energy Rev 2021;143:110915.

[72] Lesic V, Bruine de Bruin W, Davis MC, Krishnamurti T, Azevedo IML. Consumers' perceptions of energy use and energy savings: a literature review. Environ Res Lett 2018;13:033004.