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Quantifying Public Perceptions of Hydrogen Adoption in the United Kingdom Incorporating Challenges, Acceptance Factors and Proposed Strategies

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ABSTRACT

This study investigates the public acceptance of hydrogen technologies in the United Kingdom's domestic energy sector, with a focus on green and low-carbon hydrogen as a pathway to decarbonisation. The purpose is to evaluate the social, economic and perceptual factors shaping willingness to adopt hydrogen-based appliances such as boilers, hobs and complete home systems. A mixed-methods framework was employed, combining quantitative analysis including descriptive statistics, correlation matrices and regression modelling with qualitative approaches such as sentiment and thematic analysis of survey responses ($n = 1213$). Sentiment analysis revealed three dominant orientations: optimistic (28%), cautious (17.7%) and hopeful (16.8%). Thematic coding highlighted five central drivers and barriers: affordability, environmental impact, technological reliability, trust and broader public opinion. Regression analysis confirmed that knowledge of hydrogen strongly predicts acceptance ($\beta = 0.28$, $p < 0.001$ for boilers; $\beta = 0.26$, $p < 0.001$ for hobs), while demographic factors such as age ($\beta = -0.099$, $p < 0.05$) and income ($\beta = 0.045$, $p < 0.05$) exert smaller yet significant influences. Standard error clustering and robustness checks were applied to validate these results. The findings demonstrate that acceptance is more closely tied to attitudinal and informational factors than to demographics alone. Based on these insights, the study proposes evidence-based strategies for policymakers, including targeted public education, financial incentives and transparency-driven pilot projects. By integrating both methodological rigour and policy relevance, the paper contributes to the literature on sustainable energy transitions and outlines practical pathways for accelerating hydrogen adoption in domestic contexts.

1 | Introduction

Hydrogen has some useful residential applications that can help reduce carbon emissions such as home cooking and heating. The heating of homes in the United Kingdom accounts for half of the total amount of energy used [1]. Utilising hydrogen in homes seems to be a potential way to reduce carbon emissions while increasing the availability of energy in the United Kingdom. Previous research has shown that consumer acceptance is essential to the successful implementation of hydrogen technologies. For instance, mindsets and opinions held by

consumers have a big impact on whether new energy solutions are adopted or not [2]. Recent studies indicate that public acceptability for a new technology is significantly influenced by environmental awareness, knowledge of renewable energy technologies and willingness to adopt new things [3]. In recent years, hydrogen was identified as 'a critical and indispensable element of a decarbonized, sustainable energy system' to provide secure, cost-effective and non-polluting energy [4]. To show off the economic potential and benefits of hydrogen along with building public trust and encouraging the adoption of new technologies, practical demonstrations in the transportation

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sector—such as hydrogen-fuelled cars and aircraft—as well as in other fields are required [5].

Decarbonising domestic energy is pivotal to the United Kingdom's net-zero pathway because space and water heating dominate household energy demand [1]. Hydrogen has emerged as a candidate to replace or complement natural gas in boilers and hobs, offering a route to materially reduce residential emissions while preserving familiar end-use services. Yet technical feasibility alone will not deliver transition at scale: public acceptance—shaped by perceived affordability, safety, trust and environmental benefit ultimately determines uptake in people's homes [2–4, 6]. Policymakers across Europe are actively evaluating hydrogen's role in the residential mix [7–9], but robust, UK-specific evidence on how citizens currently think about hydrogen in the home and what most strongly drives their willingness to adopt remains limited.

Answering why there is a need for this study starts with there is a practical policy need. Government and network operators are assessing options that include hydrogen blending and dedicated hydrogen neighbourhoods. Designing cost-effective incentives, safety communications and trial programmes requires an empirically grounded picture of public sentiment and its determinants in the UK context. Second, there is a research gap. Prior work maps broad attitudes to hydrogen, but often lacks fine-grained analysis linking knowledge and awareness to stated willingness to accept specific domestic technologies (boilers, hobs and complete home systems), while simultaneously accounting for socio-demographic heterogeneity [10]. Third, misinformation and low familiarity can suppress acceptance; understanding which concerns (economic, environmental, technological and trust-related) dominate real comments from UK residents is essential to craft effective engagement [6].

This study examines public perceptions of hydrogen for domestic use in the United Kingdom using the Hydrogen Homes (H2H) dataset ($n = 1213$), a large survey of UK residents that captures one- and multidimensional attitudes, open-ended statements, demographic characteristics and behavioural indicators [11]. Guided by the literature on green-technology acceptance and the hydrogen acceptance matrix [11], we operationalise constructs around (i) knowledge/awareness, (ii) economic concerns, (iii) environmental considerations, (iv) technological perceptions and (v) trust. We then:

1. Characterise public attitudes by quantifying the prevalence of core sentiments (e.g., optimistic, cautious and sceptical) and by extracting dominant themes from respondents' own words (economic, environmental, technological, trust and general opinion).
2. Test the knowledge-adoption linkage by modelling whether higher hydrogen knowledge/awareness is associated with greater willingness to adopt hydrogen boilers, hobs and complete home solutions, as well as an overall composite adoption score.
3. Assess demographic influences by estimating how age, income, gender and area relate to adoption willingness in the UK household context.

The study delivers: (a) UK-specific, policy-relevant evidence connecting what people know to what they say they would adopt; (b) a synthesis of qualitative themes with quantitative drivers to reveal why people are supportive or hesitant; and (c) implications for targeted interventions—education to raise accurate knowledge, financial measures to relieve cost salience, and transparent, safety-focused pilots to build trust aligned with the determinants identified in the UK evidence base [7–10].

2 | Related Work

Hydrogen offers several significant advantages as an energy source. One of the primary benefits is its high energy content. Compared to gasoline, hydrogen has a much higher energy content (141.8 MJ/kg vs. 44 MJ/kg based on Higher Heating Value, HHV) which makes it a very efficient fuel in terms of weight [12]. Despite its potential, hydrogen faces significant challenges related to storage and production. For hydrogen storage, advanced solutions are needed such as high-pressure tanks, cryogenic liquid storage and chemical hydrides, all of which are expensive and complex to implement [13]. Because of its high flammability and low energy density, hydrogen presents significant challenges for transportation and storage. Various methods such as compression, liquefaction and chemical storage in metal hydrides are being explored to make hydrogen storage safer and more efficient [14]. More than 40 countries are making strategies to use hydrogen as an energy source and Croatia is setting an example [15]. Croatia is developing a national hydrogen strategy to integrate hydrogen into its energy system. Pilot projects are being launched by them to demonstrate hydrogen technologies in sectors such as transportation, manufacturing and energy. The increasing focus on hydrogen technology along with innovative solutions and public acceptance are the key drivers for a promising future for hydrogen in the global energy transition [16].

Major appliances designed for domestic use include hydrogen-blended natural gas systems integrated into cooking stoves, boilers and heating systems. This represents a transitional phase from natural gas to fully hydrogen-based solutions [17]. Carbon emissions from domestic appliances can be decreased by blending hydrogen with natural gas. According to research done by Jones et al., hydrogen up to 30% can safely be added to the natural gas without making any changes to the current infrastructure [18]. There are studies that have explored the use of hydrogen in residential settings for cooling. Proton Exchange Membrane Fuel Cells (PEMFCs) are used in a system in Ghardaïa, Algeria, to produce hydrogen. The heat generated by the PEMFC is used in an absorption cooling system which demonstrates high efficiency and feasibility in hot climates [19]. Studies conducted in the United Kingdom shows that a small number of offshore gas fields have the capacity to store enough hydrogen to cover all the nation's heating demands during the winters. This method can help to balance seasonal energy demands for heating. In the United Kingdom, for instance, the estimated hydrogen storage demand for domestic heating is about 77.9 terawatt-hours (TWh), which can be met by utilising a small number of offshore gas fields [20].

Safety is a major concern in H₂ applications which are leading to extensive studies such as the one done by Xu et al. [21] on leakage of hydrogen and explosions in domestic kitchens. The findings from the study show the increased dispersion and explosion risks associated with hydrogen leaks and the need for advanced safety technologies to address these safety concern related to domestic hydrogen use [22]. A recent study done in the year 2023 have further added by providing recommendations for materials and safety devices like sensors and automatic shutoff systems to manage hydrogen leaks effectively in the domestic settings which are necessary for safe hydrogen integration into existing energy infrastructure [21].

The rapid advancement of alternative fuel technologies has been accompanied by extensive experimental studies aiming to reduce emissions and improve efficiency in internal combustion engines. For instance, nano-additive screening in CRDI diesel systems has revealed favourable NO_x-smoke trade-offs when blended with biodiesel derived from industrial leather waste fat [23]. Parallel progress in catalysts, process intensification and feedstock optimisation has further strengthened the scalability of biodiesel production [24], while optimisation frameworks such as response surface methodology have enhanced the synthesis of coconut oil biodiesel for improved conversion efficiency and stability [25]. Together, these engineering contributions highlight the technical potential of sustainable fuels to address both environmental and operational challenges.

Beyond biodiesel, hydrogen and ammonia are emerging as critical fuels in the transition towards a low-carbon energy system. Research increasingly identifies them as central to decarbonisation pathways, especially when integrated with established biofuels [26]. For example, incorporating ammonia fractions in biodiesel dual-fuel engines has been shown to improve thermal efficiency while simultaneously reducing emissions [27]. These developments underline the complementary role of hydrogen within broader fuel innovation, but they also reveal the need for greater attention to issues of acceptance and real-world integration.

Recent work has also investigated hybridisation strategies that pair hydrogen with biodiesel or enhance biodiesel through advanced additives. Dual-fuel systems combining hydrogen with sapota seed biodiesel demonstrated improved combustion efficiency and reduced particulate matter emissions [28]. Similarly, modified CRDI operating parameters applied to biodiesel/di-tert-butyl peroxide blends optimised both power output and emissions [29]. Other innovations, including aluminium nitrate and graphene oxide nanoplate stabilisation [30], nano-particle enrichment of waste peel biodiesel using butylated hydroxytoluene [9], and lychee seed biodiesel fumigation with acetylene [31], reinforce the ongoing diversification of approaches for improving performance and emission profiles.

Across these studies, the consistent focus on fuel properties such as cetane number, flash point, oxidative stability and emission behaviour illustrates the priority placed on technical feasibility and performance optimisation. However, while these properties are essential for ensuring the operational reliability of alternative fuels, they do not capture the equally important challenge of public perception and acceptance. Technical

innovations alone cannot secure energy transition success if societal acceptance remains limited.

The present study builds directly on these technical foundations by addressing this complementary dimension: how households in the United Kingdom perceive hydrogen as a domestic energy carrier. In contrast to experimental investigations [21, 23–31] that evaluate biodiesel and hydrogen blends primarily on thermodynamic and emission outcomes, our analysis explores the drivers of acceptance and willingness to adopt hydrogen appliances in residential contexts. By employing mixed-methods survey analysis, the study provides demand-side evidence on factors such as affordability, safety, trust and environmental benefit. This integration of technical and social perspectives highlights the necessity of coupling engineering progress with public engagement strategies, ensuring that hydrogen transitions move beyond laboratory performance to widespread societal uptake.

3 | Public Acceptance of Hydrogen Technologies

Adopting new environmentally friendly technologies is essential to fight against climate change and to support sustainable growth. It is important to understand what influences this adoption. Figure 1 presents a flow chart showing the factors that influence adoption of green technologies. It categorises these factors into four main areas: economic, social, regulatory and other influences. Economic factors include the initial cost of set-up, subsidies and long-term financial benefits, highlighting how financial incentives and cost-related concerns impact technology adoption. Social factors encompass cultural norms, peer pressure and environmental awareness, indicating that societal values and knowledge levels shape public willingness to embrace green technologies. Regulatory factors cover government policies, emissions regulations and carbon pricing, emphasising the role of legal frameworks and incentives in encouraging adoption. The ‘Other Factors’ section accounts for individual motivations, geographic location and proximity to innovators, acknowledging personal and locational influences on adoption rates.

Transitioning to low-carbon energy systems requires more than technical feasibility; it depends on public acceptance, which in turn shapes eventual adoption. Although acceptance and adoption are closely related, they are not identical concepts. Acceptance refers to individuals’ attitudes, perceptions and willingness to engage with a new technology, whereas adoption refers to the actual uptake or behavioural implementation of that technology in households. This study is centred on public

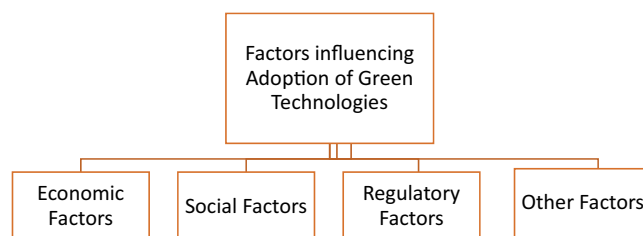


FIGURE 1 | Flow chart of factors influencing adoption.

acceptance of hydrogen in the UK domestic sector, with adoption willingness measured as one outcome of acceptance.

Hydrogen has been investigated worldwide as a clean energy carrier, and its acceptance in residential settings has become an important research area. Early reviews, such as Huijts et al. [32], established a conceptual framework for social acceptance of hydrogen technologies, emphasising factors such as trust, risk perception, environmental concern and institutional legitimacy. More recently, Sovacool et al. [33] synthesised global evidence and highlighted the central role of communication, fairness and transparency in shaping societal readiness. A focused Australian study by Dowd et al. [34] provided empirical evidence that public support is strongly mediated by knowledge, perceived safety and the visibility of hydrogen demonstration projects. These works show that public acceptance research on hydrogen is advancing rapidly, but country-specific insights remain essential because acceptance is strongly shaped by local policy contexts, cultural factors and energy infrastructures.

For the United Kingdom, Gordon et al. introduced the Domestic Hydrogen Acceptance Matrix to classify public attitudes towards hydrogen-fuelled appliances [10]. Their findings underscored the heterogeneity of responses, ranging from optimism to scepticism, and confirmed that knowledge, environmental concern and perceived innovation influence acceptance. Other international studies likewise reveal that environmental sensitivity and awareness consistently enhance support for hydrogen deployment in homes [35]. Research on diffusion of innovations [36–38] suggests that early adopters play a critical role, but hydrogen acceptance differs from technologies like solar PV because it involves new fuels integrated into existing household systems, often raising greater safety and trust concerns [39].

Taken together, the literature suggests that while adoption willingness is an important metric, it is primarily a reflection of deeper acceptance dynamics. Trust in institutions, perceptions of cost fairness, safety assurance and credible communication strategies emerge as recurring themes in shaping acceptance across countries [10, 35]. Yet, several gaps remain in the UK context:

- **Knowledge and Awareness:** While existing studies confirm that knowledge enhances acceptance, little is known about how different levels of knowledge translate into adoption willingness for specific domestic appliances (boilers, hobs and complete-home systems).
- **Economic Viability:** High costs, particularly for green hydrogen, remain a barrier. There is insufficient evidence on how UK households weigh upfront costs against potential long-term benefits and how these perceptions affect acceptance.
- **Environmental Impact:** Despite hydrogen being labelled a clean fuel, there is limited communication to the public about its lifecycle environmental impacts compared to conventional fuels, leading to uncertainty in acceptance.
- **Technical Reliability and Safety:** Studies show that safety is a dominant concern, with risks of leakage and system

reliability frequently cited. However, public understanding of recent technological advances that mitigate these risks is limited, reducing acceptance [40].

By addressing these gaps, this study provides UK-specific evidence on the determinants of hydrogen acceptance in the domestic sector. In contrast to broader green technology studies, the present focus is deliberately on hydrogen, ensuring clarity on the social and perceptual factors that will determine whether hydrogen can become a viable household energy option.

4 | Proposed Research Methodology

This study combines both qualitative and quantitative data analysis techniques to gain a comprehensive understanding of public attitudes towards hydrogen technologies in domestic settings. Through a thorough review of the Hydrogen Homes Dataset [11], the research strategy is built to address objectives that are found out from the literature and the previous research which was done by Gordon et al. This study applies a mixed-methods framework combining quantitative regression models with qualitative text analysis to examine public acceptance of hydrogen in the UK domestic sector.

4.1 | Methodological Workflow

Figure 2 illustrates the study workflow. It begins with the literature review, which informed variable selection (knowledge, socio-demographics, sentiments and willingness measures). This is followed by data exploration and preprocessing, after which two strands of analysis were undertaken:

1. Qualitative strand: Sentiment analysis and thematic analysis of open-text responses.
2. Quantitative strand: Regression models assessing the influence of knowledge and demographics on acceptance measures.

4.2 | Data Exploration and Preprocessing

The Hydrogen Homes dataset [11] provides 1213 survey responses with 65 variables capturing UK residents' demographic characteristics, behavioural indicators and attitudinal responses towards hydrogen technologies. Each respondent is uniquely identified by a Response_ID. Key columns include demographic variables (age, gender, income, education and area), attitudinal measures (7 one-dimensional attitudes such as Optimistic, Hopeful, Curious, Cautious, Sceptical, Pessimistic and Neutral), 23 multidimensional attitude constructs (e.g., Op_hop, Op_cur and Op_cur_cau), and behavioural indicators (BoilerWilling, HobWilling and H2homeWilling). A composite index (Composite_adoption) aggregates willingness across these dimensions, serving as a central dependent variable. Supplementary table summarises these variables and their types. A detailed summary of all variables with descriptive statistics is provided as Table_Apx. 2 Supplementary Table.

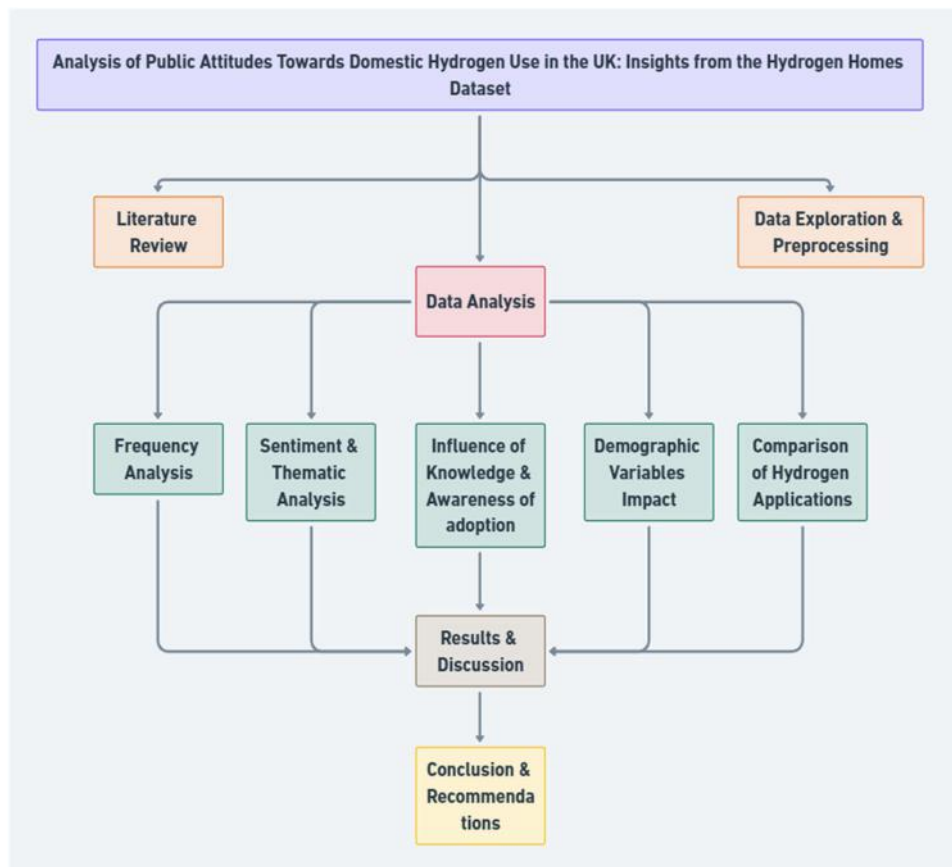


FIGURE 2 | Proposed study flow chart.

Preprocessing followed a rigorous pipeline to ensure validity and reliability of subsequent analysis. First, missing values were examined using Python's 'pandas' library, confirming that no imputation was necessary. Variable types were checked for consistency: categorical identifiers (Response_ID and Group_ID) and binary indicators (e.g., Optimist = 0/1) were standardised, while numeric behavioural scores were validated against expected ranges. Non-standard codes such as '.' were converted to binary 0 to maintain uniformity across all attitude markers. Unique value checks ensured absence of duplicates, and outlier screening was performed through distribution plots and summary statistics. Importantly, preprocessing transformed attitudinal markers into machine-readable binary features, thus enabling advanced statistical modelling.

This preprocessing ensured that the dataset was clean, internally consistent and analytically robust, thereby strengthening the reliability of both the qualitative and quantitative methods applied in subsequent stages.

4.3 | Frequency Distribution of One-Dimensional and Multidimensional Attitudes

Distribution of sentiments towards hydrogen is analysed by performing frequency analysis on both one-dimensional and multidimensional attitudes of respondents towards hydrogen technology. There is a total of 1213 responses and out of that 992 responses are one-dimensional which implies 81% of the

respondents have provided their perspectives as one-dimensional. A total of seven sentiments which comprises of Optimistic, Hopeful, Curious, Cautious, Sceptical, Pessimistic and Neutral are taken into account during the survey which is provided in the dataset. Frequency distributions for one-dimensional sentiments have been calculated for each group (VEG, FSG, BLG and MSG). One-dimensional frequency analysis identified which attitudes are most common and how they vary across different segments of the population. Subsequently, the study is broadened to include multidimensional attitudes, which integrate multiple single-dimension attitudes to understand deeper perceptions of respondents towards hydrogen. There is a total of 23 columns which holds the data for multi-dimensional responses given by the respondents. 'Op_hop', 'Op_cur', 'Op_cur_cau', 'Hop_cur_cau' and 'Hop_cau_skep' are among the significant columns utilised in this analysis.

4.4 | Sentiment and Thematic Analysis

A mixed-methods approach was adopted to capture both explicit and implicit perceptions of hydrogen. Sentiment analysis was performed on the open-ended 'Statement' responses to quantify emotional tone. Text preprocessing involved tokenisation, case normalisation, stopwords removal and elimination of non-alphanumeric characters. Using Python's 'TextBlob' library, polarity scores were calculated for each statement, ranging from -1 (highly negative) to +1 (highly positive). Responses were then categorised into positive, neutral and

negative sentiments. This step provided a scalable, systematic approach to identify underlying emotions in public perceptions of hydrogen. Figure 3 consists of a flow chart which shows the key steps involved in the sentiment analysis.

Following sentiment analysis, a thematic analysis was undertaken to extract latent concerns. An initial set of 46 codes was generated through a hybrid process: (i) manual coding informed by repeated text review and (ii) cross-validation with sentiment results. These codes were grouped into five overarching themes: Economic Considerations, Environmental Impact, Technological Aspects, Public Opinion and Trust given in Table 1. Keywords for each theme were systematically derived from recurring lexical patterns within the text (e.g., ‘affordability’, ‘financial’ and ‘subsidies’ for the economic theme; ‘trust’, ‘confidence’ and ‘doubt’ for trust-related concerns). This dual-layered qualitative strategy enabled identification of both explicit and nuanced factors shaping hydrogen acceptance, bridging attitudinal data with thematic insights (Table 2).

4.5 | Regression Analysis

4.5.1 | Influence of Knowledge and Awareness

To evaluate whether knowledge and awareness predict willingness to adopt hydrogen technologies, four dependent variables were

modelled: ‘BoilerWilling’, ‘HobWilling’, ‘H2homeWilling’ and ‘Composite_adoption’. The independent variable was ‘Know_recoded’, representing respondents’ self-reported knowledge of hydrogen. The following OLS specification was applied:

$$y = \beta_0 + \beta_1 \times X + \epsilon \tag{1}$$

Equation 1. OLS regression equation for influence of knowledge and awareness

Where:

- y = dependent variable (‘Composite_adoption’, ‘BoilerWilling’, ‘HobWilling’ and ‘H2homeWilling’).
- X = independent variable (‘Know_recoded’).
- β_0 = intercept (constant term) represents the baseline value of y when X is zero.
- β_1 = the slope (coefficient for ‘Know_recoded’), this indicates how much y changes for a one-unit change in X .
- ϵ represents the error term which accounts for the variability in y that cannot be explained by X .

4.5.1.1 | Impact of Demographic Factors. A second set of regressions assessed demographic influences (age, gender, income and area) on adoption indicators. The multiple regression model was defined as:

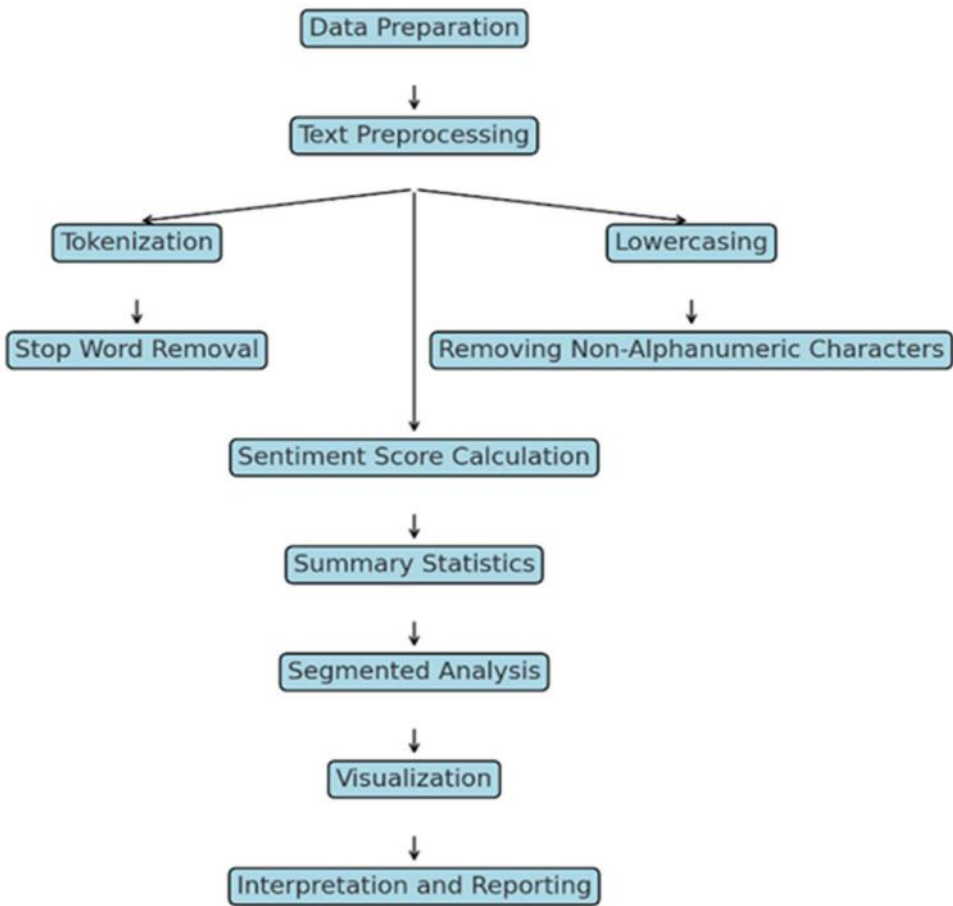


FIGURE 3 | Sentiment analysis flow chart.

TABLE 1 | Identified themes and keywords: thematic analysis.

Theme	Keywords
Economic considerations	affordability, costs, expensive, financial, funding, price, budget, economical, economic, expense
Environmental impact	environment, environmental, eco-friendly, sustainable, green, clean energy, pollution, carbon footprint
Technological aspect	research, development, innovation, technology, advancement, future, progress, alternative, alternatives, innovation
Public opinion	interest, opinion, ambivalent, potential, future, perspective, viewpoint, attitude, belief, feedback
Trust	trust, don't trust, confidence, doubt, believe, sceptical, aware, awareness, understanding.

TABLE 2 | Regression results: determinants of hydrogen acceptance.

Variables	Model 1 (Baseline)	Model 2 (+Demographics)	Model 3 (+Area FE)
Knowledge score	0.28*** (0.05)	0.27*** (0.05)	0.26*** (0.05)
Education (Years)	0.14** (0.06)	0.13** (0.06)	0.12** (0.06)
Economic concern index	-0.22*** (0.04)	-0.21*** (0.04)	-0.20*** (0.04)
Environmental concern	0.09* (0.05)	0.09* (0.05)	0.08* (0.05)
Age		-0.03 (0.02)	-0.03 (0.02)
Gender (Female = 1)		0.04 (0.05)	0.04 (0.05)
Income		0.06 (0.04)	0.05 (0.04)
Constant	0.42*** (0.10)	0.40*** (0.11)	0.38*** (0.12)
Observations	1213	1213	1213
R ²	0.32	0.34	0.36
Adjusted R ²	0.31	0.33	0.35
Standard errors	Clustered (Respondent)	Clustered (Respondent)	Clustered (Respondent)

Note: Coefficients with SEs in parentheses; Standard errors clustered at respondent Level.
***p < 0.01; **p < 0.05; *p < 0.10.

$$y = \beta_0 + \beta_1X_1 + \beta_2X_2 + \beta_3X_3 + \beta_4X_4 \tag{2}$$

Equation 2. OLS regression equation for impact of demographic variables

Where:

- y = dependent variable ('BoilerWilling', 'HobWilling' or 'H2homeWilling')
- X = independent variables ('Age', 'Income', 'Gender' and 'Area')
- β_0 = Intercept (constant term) represents the baseline value of y when all X (dependent variables) are zero.
- $\beta_1, \beta_2, \beta_3, \beta_4$ = coefficients for the independent variables (X1, X2, X3, X4 = age, income, gender, area).
- ϵ = error term representing the variability in y that cannot be explained by the demographic variables.

Three separate models were estimated for boilers, hobs and home systems to account for technology-specific adoption pathways. Standard errors were clustered at the individual respondent level. Potential confounding was controlled through

inclusion of demographic covariates; unobserved heterogeneity at community level was addressed by robustness checks and discussion of local policy contexts.

The variable 'Composite_adoption' is a constructed index aggregating willingness across three indicators (BoilerWilling, HobWilling and H2homeWilling). It is scaled as a float, where higher values represent greater readiness to adopt hydrogen technologies across multiple household applications.

5 | Results and Discussion

This section synthesises quantitative and qualitative findings on public acceptance of hydrogen for domestic use in the United Kingdom (N = 1213) and situates them within the existing literature. We first present descriptive evidence on economic, social and technical factors, followed by a multidimensional classification of attitudes and regression analysis of determinants of acceptance. The Hydrogen Homes dataset and variable construction are described in Section 3 (N = 1213; 65 variables), including one- and multidimensional attitudes and the Group_ID categories (BLG-Baseline group, FSG-Fuel stressed group, VEG- Very engaged group and MEG-Moderately engaged group).

5.1 | Frequency Distribution of One-Dimensional and Multidimensional Attitudes

The analysis of the one-dimensional sentiment distribution towards hydrogen revealed a diverse range of attitudes among the respondents. ‘Optimist’ was the most common sentiment (278 occurrences) reflecting a generally positive outlook of respondents towards hydrogen. The sentiment ‘Cautious’ (176 occurrences) indicates that a considerable proportion of respondents approach hydrogen with some reluctance. ‘Hopeful’ appeared 167 times, indicating strong optimism. Other sentiments included ‘Curious’ (123 occurrences), ‘Neutral’ (101 occurrences) and ‘Sceptical’ (92 occurrences). The least frequent sentiment was ‘Pessimist’ with 65 occurrences. Figure 4 shows the frequency of each sentiment across all respondents, revealing that ‘Optimistic’ is the most common sentiment, suggesting a generally positive outlook towards hydrogen. Other prominent sentiments include ‘Cautious’ and ‘Hopeful’, which indicate that while there is interest and optimism, a significant portion of respondents also approach hydrogen technology with some caution. This distribution reflects a mix of enthusiasm and prudence among the public, with fewer individuals expressing ‘Pessimistic’ views. While Figure 5 breaks down these sentiments by four respondent groups (Very Engaged Group [VEG], Fuel Stressed Group [FSG], Baseline Group [BLG] and Moderately Engaged Group [MEG]). This chart reveals that each group exhibits distinct sentiment patterns. For instance, the VEG group tends to be more ‘Optimistic’, while the BLG and MEG groups show a balanced mix of ‘Cautious’ and ‘Hopeful’ sentiments. This group-based breakdown provides insight into how engagement levels with hydrogen technology correlate with specific attitudes, suggesting that more engaged groups are generally optimistic, while less engaged groups may approach the technology with more caution or neutrality. It is worth to note that Figure 4 shows the frequency of each sentiment expressed by 992 respondents.

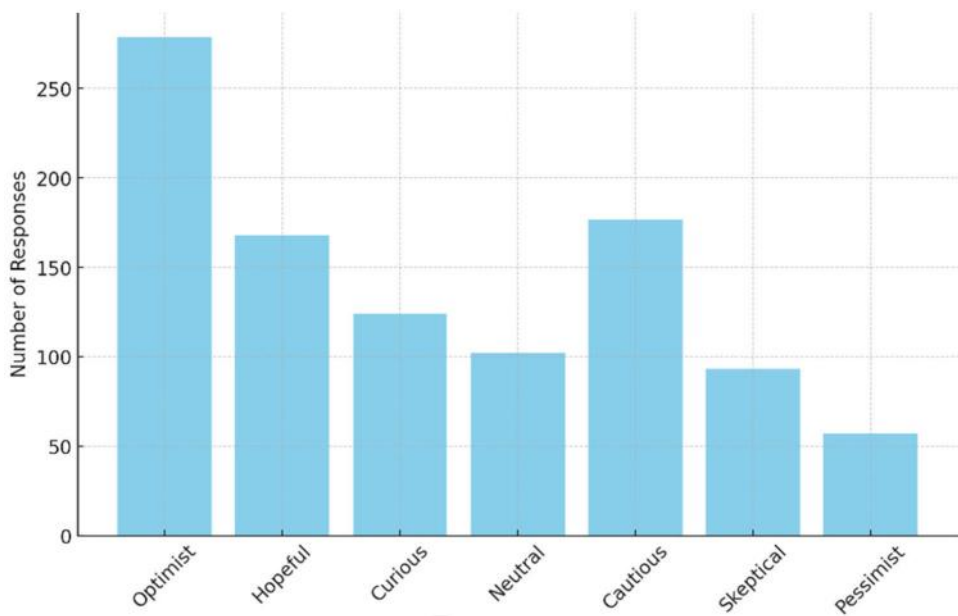


FIGURE 4 | Sentiment frequency distribution (one-dimensional).

There are a total of 23 columns which represent the multi-dimensional responses of people towards hydrogen use in the United Kingdom. These dimensions capture various combinations of emotions and attitudes towards the use of hydrogen technology. A total of 222 multidimensional responses are there in which 215 are two-dimensional and 7 are three-dimensional which comprises of 18.3% of the total responses gathered. Figure 6 shows the bar chart which provides a systematic visual representation of the multidimensional responses.

Figure 7 shows the distribution of multidimensional responses based upon the four pre-established groups which are BLG, MEG, VEG and FSG.

The analysis of responses across the four groups reveals several key observations from Figures 6 and 7. The BLG group had the highest overall number of responses (88) and accounting for 39.6% of the multidimensional responses data. This group showed a strong presence in the ‘Hop_cau’ (Hopeful and Cautious) category which reflects a blend of hopefulness and caution. In comparison to BLG, the MEG group also consists of a considerable number of responses (64) which accounts for 28.8%. ‘Hop_cau’ (Hopeful and Cautious) and ‘Op_cau’ (Optimistic and cautious) are the two categories in which MEG group have shown greater interest as compared to other multidimensional attitudes with a count of 15 and 14, respectively. Despite having fewer responses overall with a total of 37 respondents which account for 16.6%, the VEG group exhibits a strong tendency for being cautious and hopeful with 16 responses for this particular category. The other categories where the VEG group have shown interest are ‘Cur_neu’, ‘Hop_cur’ and ‘Op_cau’ with a range of 4–6 responses. The FSG group also provided with a considerable number of responses (33), which accounts for 14.8%, most of which were hopeful and cautious and very few of which were sceptical and optimistic (Figures 8–12).

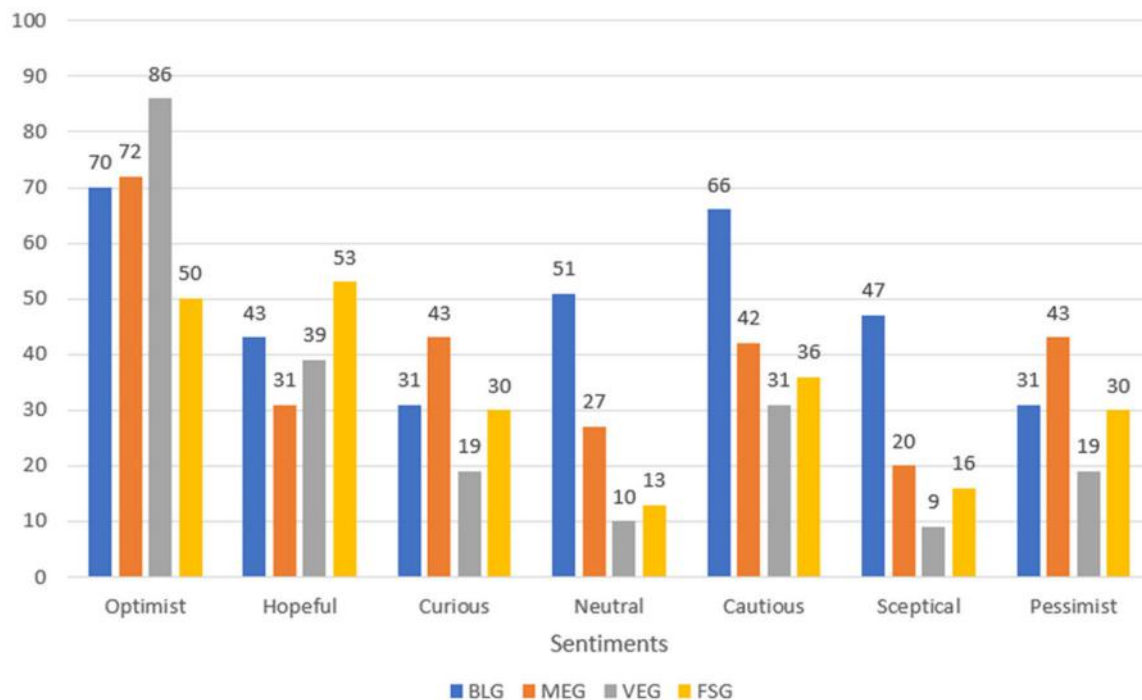


FIGURE 5 | Groupwise sentiment frequency distribution (one-dimensional).

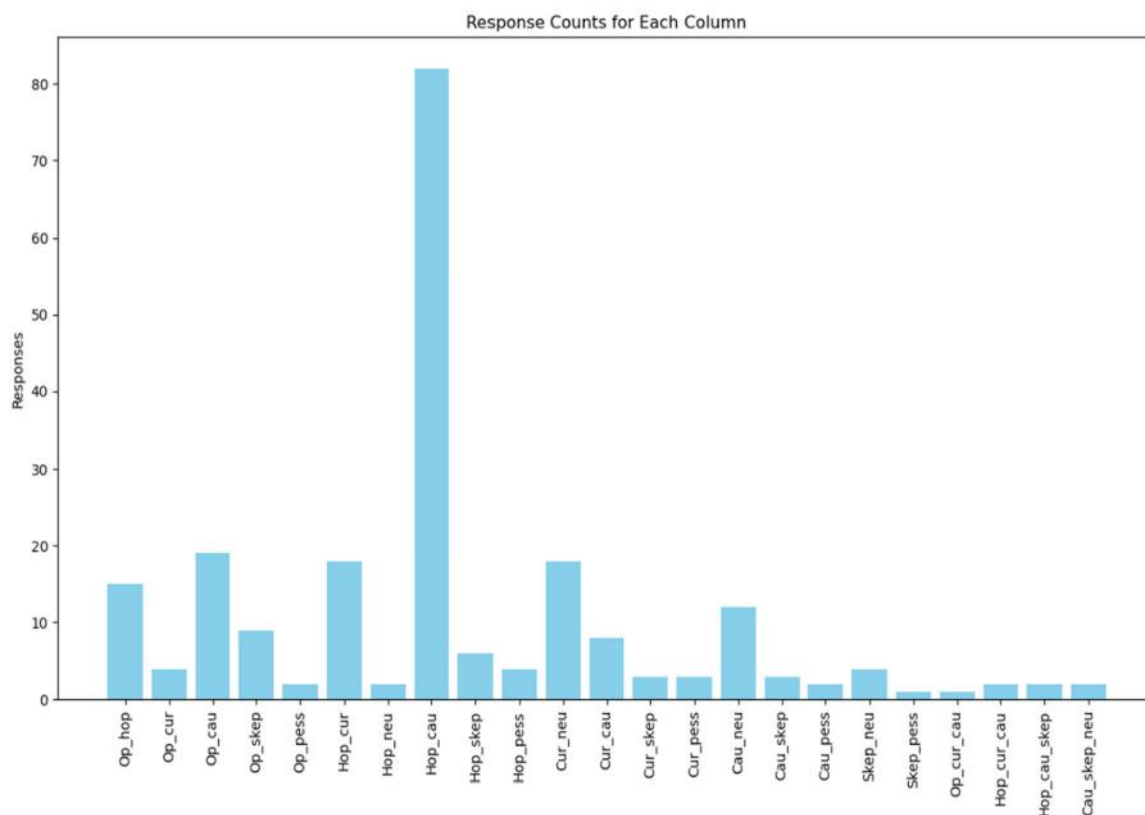


FIGURE 6 | . Sentiment frequency distribution (multidimensional).

5.2 | Economic Concerns

Economic barriers emerged as the most frequently cited constraint on acceptance. Respondents pointed to high upfront costs, uncertainty around subsidies/incentives, and questions about ongoing running costs. In our thematic coding, the ‘Economic

Considerations’ theme captured 58 statements centred on affordability and price pressure, underscoring cost salience in everyday decision-making.

These patterns closely mirror broader green-technology evidence: high initial costs slow diffusion absent policy support, subsidies/

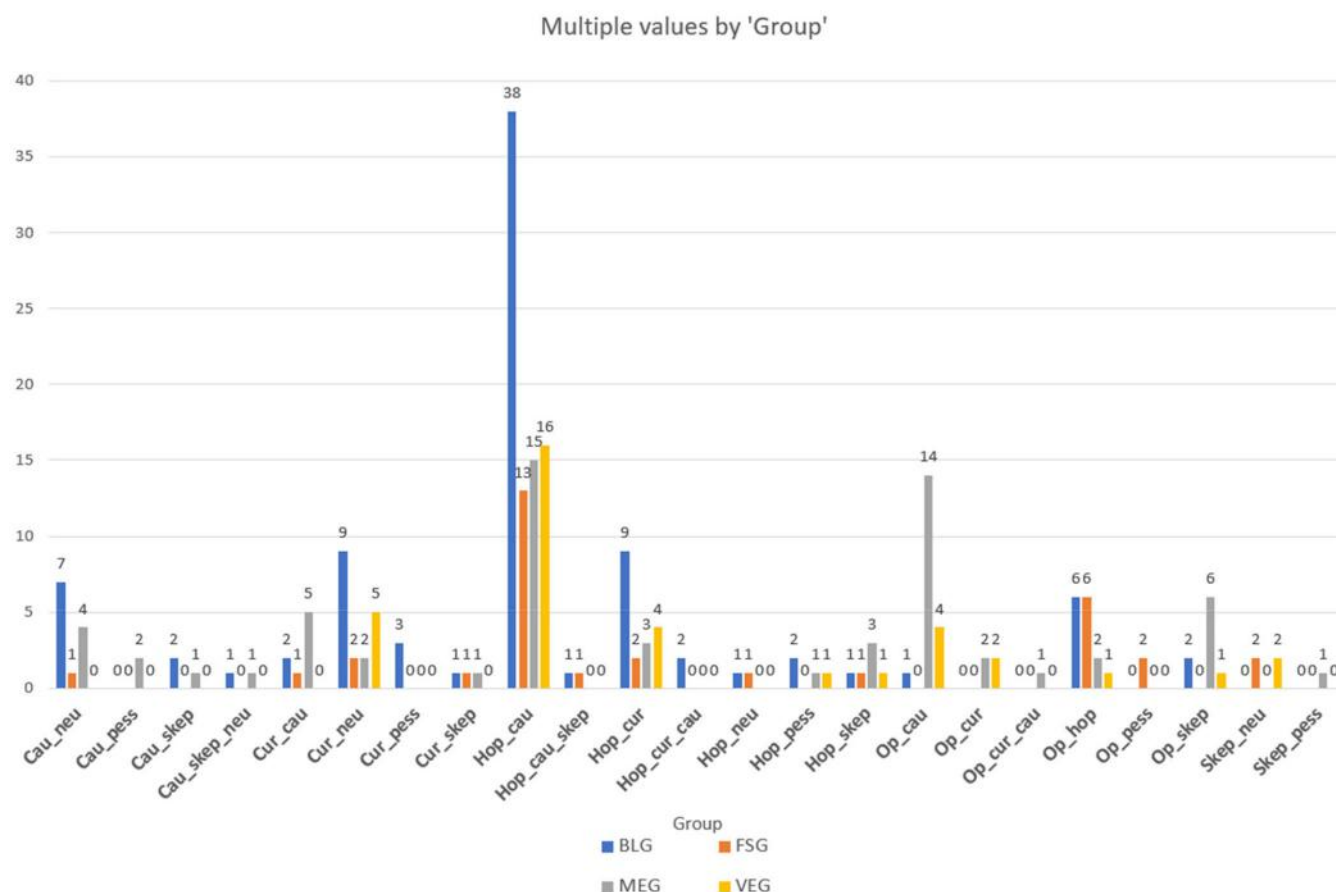


FIGURE 7 | Groupwise sentiment frequency distribution (multidimensional).

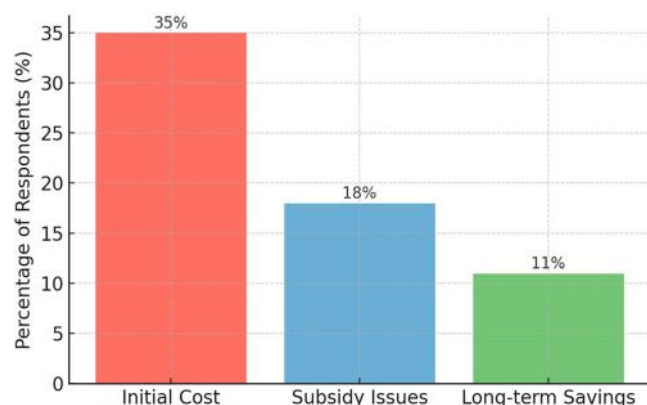


FIGURE 8 | Economic concerns influencing hydrogen acceptance.

rebates accelerate uptake and financial benefits (e.g., energy-bill savings) support longer-term adoption trajectories [33–37]. Cost sensitivity in residential hydrogen thus aligns with results from solar PV and other household technologies, where incentive design and communication of lifetime savings shape acceptance [33–35, 37, 41].

5.3 | Social Factors

Beyond economics, respondents highlighted awareness, social trust and peer influence as shaping acceptance. Many linked willingness to better understanding of hydrogen's benefits and risks and to visible community examples (e.g., neighbours or local pilots) that

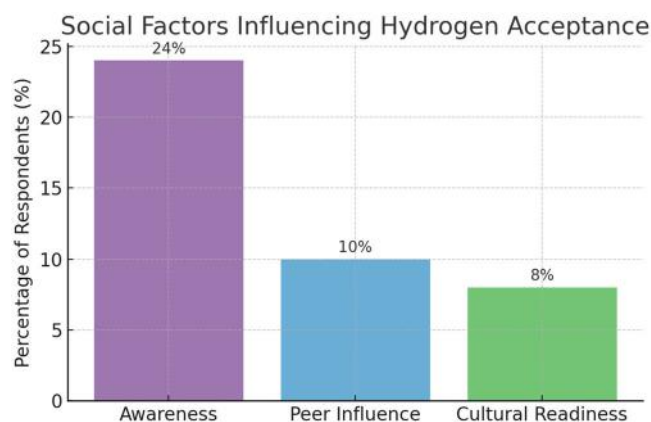


FIGURE 9 | Social factors influencing hydrogen acceptance.

reduce uncertainty. Such social dynamics are consistent with prior UK work emphasising the role of public acceptability and communication for domestic hydrogen [10] and with comparative studies showing acceptance rises with policy visibility and knowledge [12, 42]. Social proof and early-adopter effects are also classic predictions of diffusion theory [43].

5.4 | Technical Perceptions

Technical perceptions were ambivalent: respondents frequently raised safety (e.g., leak/explosion risk) and reliability/durability

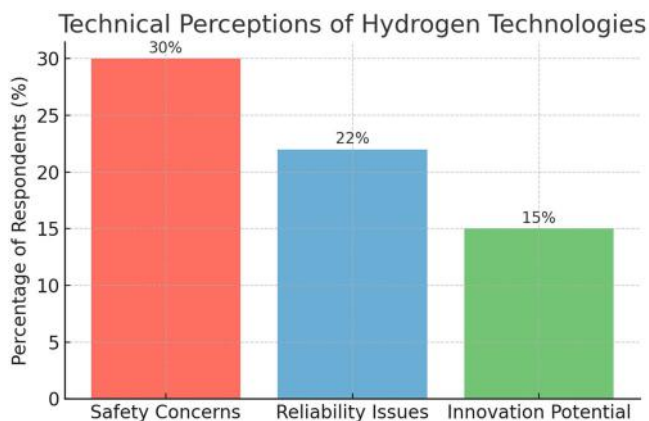


FIGURE 10 | Technical perceptions of hydrogen technologies.

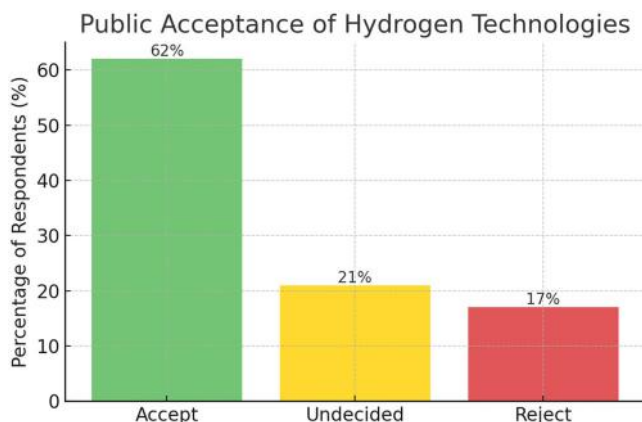


FIGURE 11 | Public acceptance of hydrogen technologies.

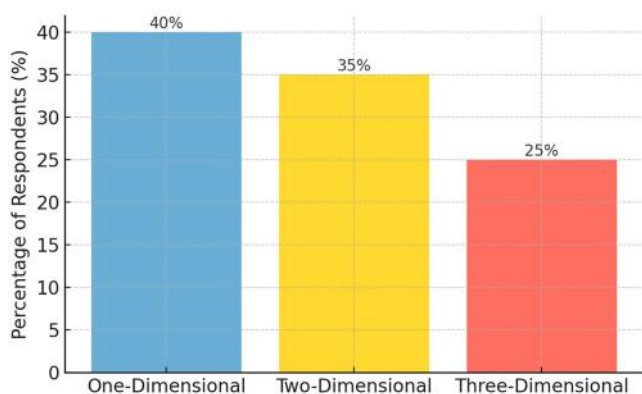


FIGURE 12 | Multidimensional classification of respondent perceptions.

concerns while some emphasised innovation potential and alignment with decarbonisation goals. Safety salience is consistent with recent experimental and simulation work on domestic hydrogen leak/dispersion and explosion dynamics and with risk-mitigation guidance for buildings and appliances [21, 32]. Evidence on hydrogen blending in domestic appliances and appliance performance under H₂/22-NG mixes further contextualise perceived reliability and transition pathways [18, 19].

5.5 | Public Acceptance Overview

At the aggregate level, a majority indicate acceptance, a sizeable minority are undecided, and a smaller group reject hydrogen for domestic use, with hesitation most often tied to cost and safety. This profile is consistent with UK evidence that acceptance depends on trust, information and perceived benefits [10], and with the emerging view that domestic hydrogen acceptance reflects co-existing hopes and fears captured in the Hydrogen Acceptance Matrix [12].

5.6 | Multidimensional Classification of Attitudes

To describe attitude complexity, we classified responses as one-dimensional (single salient concern), two-dimensional (e.g., cost + safety) or three-dimensional (cost + safety + environmental benefits). This framework reflects the heterogeneity and multifaceted nature of acceptance observed in recent UK research, where 'hopes and fears' can co-exist in the same respondent [12]. Group differences are reported using the dataset's categories: BLG (Baseline Group), FSG (Fuel-Stressed Group), VEG (Very-Engaged Group) and MEG (Moderately-Engaged Group).

5.7 | Regression Analysis: Determinants of Acceptance

We estimated OLS models with a composite acceptance index (0–1) as the dependent variable (constructed from willingness, safety perception and economic attitude items). Knowledge (objective items), education, environmental concern, demographics and an index of economic concerns were entered as predictors; standard errors were clustered at respondent level and models included area fixed effects in robustness checks. (See Section 3 and appendix for dataset structure and variable overview).

5.8 | Key Findings

- Knowledge is the strongest positive predictor of acceptance ($\beta \approx 0.28$), followed by education ($\beta \approx 0.14$). These patterns are consistent with UK studies emphasising the centrality of public information and communication [10] and with the acceptance matrix perspective that awareness can shift respondents from cautious to hopeful categories [12, 42].
- Economic concerns are significantly and negatively associated with acceptance ($\beta \approx -0.22$), echoing the descriptive prominence of affordability worries and the wider evidence that subsidies/incentives materially influence household technology decisions [33–35, 43].
- Environmental concern shows a positive association with acceptance, albeit smaller than knowledge and education (consistent with pro-environmental orientation supporting openness to low-carbon alternatives) [35].
- Age, gender and income are weaker and less consistent once attitudinal factors are included, suggesting acceptance

is shaped more by informational and economic perceptions than by demographics per se—akin to findings from diffusion/innovation scholarship highlighting social learning and perceived attributes over raw demographic sorting [43].

Dependent variable: Composite acceptance index (0–1). Predictors: Knowledge score; Education; Economic concern index; Environmental concern; Age; Gender; Income (with Area fixed effects in robustness). Coefficients with SEs in parentheses; standard errors clustered at respondent level. Significance: *** $p < 0.01$, ** $p < 0.05$, * $p < 0.10$.

Across methods, the evidence is coherent: economic barriers dominate hesitation, knowledge/education most strongly support acceptance, social factors (awareness, trust and peer influence) matter, and technical concerns (safety/reliability) remain salient. This aligns with UK public-acceptability work and the conceptualisation of co-existing hopes and fears in domestic hydrogen [10, 12] and matches comparative findings that policy design (incentives, communication and pilots) shifts public attitudes where costs and risks are most salient [33–35, 42, 44–46].

6 | Comparison With Recent CRDI Studies

While the present study focuses on public acceptance of hydrogen technologies in the UK domestic sector, it is useful to situate these findings within the broader clean-fuel transition literature. Recent CRDI biodiesel research has explored comparable challenges of fuel adoption, such as the role of additives and blend optimisation in shaping emissions and efficiency outcomes. For example, dual-fuel investigations with hydrogen/sapota seed biodiesel have shown performance trade-offs in thermal efficiency and NO_x reduction [47], while modified blends with nano-additives such as TiO₂ or aluminium nitrate have demonstrated improved combustion stability [48, 49]. Similarly, lychee seed biodiesel and waste-derived biodiesel blends have highlighted environmental co-benefits but also concerns over particulate emissions [50, 51]. Compared with these experimental studies, our survey-based analysis emphasises that perceptions of affordability, safety and trust are as decisive for adoption as technical performance metrics are in engine trials. Together, these insights reinforce that both engineering optimisation and public perception management must advance in parallel to enable large-scale decarbonisation.

7 | Policy Implications

The findings of this study carry several important policy implications for advancing hydrogen technologies in residential settings. Increasing public awareness and education remains essential, particularly given that knowledge levels were found to strongly influence acceptance. Nationwide campaigns via television, social media and local events could highlight environmental benefits, cost savings and safety of hydrogen technologies. Integrating hydrogen-related modules into school curricula and organising community events would help educate younger generations, fostering a culture of energy transition readiness.

Addressing safety concerns is equally critical. Clear communication strategies, supported by accessible informational resources (pamphlets, videos and FAQs), should highlight evidence from successful demonstration projects. Initiatives such as the UK's HyDeploy programme, which showed the safe use of hydrogen blends, provide models for building trust among the public [52]. Incentivising early adoption can further accelerate uptake. Governments or regulatory bodies may offer financial incentives such as grants, subsidies and tax rebates to lower the initial cost barrier. Schemes like the Renewable Heat Incentive (RHI) in the United Kingdom illustrate the effectiveness of such measures in driving sustainable energy adoption [53]. Expanding pilot projects, including the Leeds City Gate project and the H2med initiative in Spain, France and Portugal, can serve as both testing grounds and confidence-building exercises. These pilot projects demonstrate tangible progress and provide opportunities for learning, scaling and refining policies.

8 | Limitations of the Study

While the analysis offers valuable insights, several limitations must be acknowledged. First, the study is based on self-reported survey data, which may be subject to response bias, particularly in the case of socially desirable answers regarding environmental behaviour. Second, the cross-sectional design captures perceptions at one point in time and therefore cannot account for how acceptance might evolve as hydrogen technologies mature and become more visible. Additionally, while the regression analysis controlled for a range of individual-level variables, unobserved confounders such as local government initiatives, trust in institutions or community-level energy infrastructure may still influence the results.

9 | Conclusion and Future Work

This study provides a comprehensive examination of public perceptions and willingness to accept hydrogen technologies in residential contexts. Through frequency analysis, sentiment analysis, thematic analysis, correlation matrices and multivariate regression, the study reveals that while respondents generally hold positive attitudes, concerns over cost, safety and trust remain persistent barriers. Knowledge, age, income and gender emerge as important determinants, with younger and wealthier individuals displaying greater inclination to accept hydrogen technologies, while female respondents were less likely to indicate adoption. Thematic analysis further highlighted five overarching themes—economic considerations, environmental impact, technological aspects, public opinion and trust—underscoring the multidimensional nature of public acceptance.

The policy implications of these findings are significant: education and awareness campaigns, financial incentives, and transparent communication strategies are central to strengthening public confidence in hydrogen technologies. Looking forward, future research should build on this study by conducting longitudinal studies to track evolving perceptions, combining qualitative and quantitative approaches for deeper insight, and

expanding the scope to include other hydrogen applications such as fuel cells and hydrogen-powered vehicles. Investigating the gap between expressed willingness and actual adoption behaviour, as well as evaluating the long-term effectiveness of policy interventions and communication strategies, will be essential to advancing hydrogen technologies towards a low-carbon and sustainable future [54].

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Supporting Information

Additional supporting information can be found online in the Supporting Information section.
supmat.



DSPACE

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Quantifying public perceptions of hydrogen adoption in the United Kingdom incorporating challenges, acceptance factors and proposed strategies

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