

Modelling the innovation-decision process for hydrogen homes: An integrated model of consumer acceptance and adoption intention

Joel A. Gordon^{a,*}, Nazmiye Balta-Ozkan^a, Anwar Ul Haq^b, Seyed Ali Nabavi^a

^a School of Water, Energy and Environment, Cranfield University, Bedford, UK

^b Newcastle Business School, Northumbria University, London, UK

ARTICLE INFO

Handling Editor: Dr S Nanda

Keywords:

Energy transitions
Green hydrogen production
Hydrogen homes
Importance-performance map analysis
Predictive modelling
Unified theory of technology acceptance

ABSTRACT

As the global energy transition progresses, a range of drivers and barriers will continue to shape consumer attitudes and behavioural intentions towards emerging low-carbon technologies. The innovation-decision process for technologies composing the residential sector such as hydrogen-fuelled heating and cooking appliances is inherently governed by the complex interplay between perceptual, cognitive, and emotional factors. In response, this study responds to the call for an integrated research perspective to advance theoretical and empirical insights on consumer engagement in the domestic hydrogen transition. Drawing on online survey data collected in the United Kingdom, where a policy decision on 'hydrogen homes' is set for 2026, this study systematically explores whether an integrated modelling approach supports higher levels of explanatory and predictive power. Leveraging the foundations of the unified theory of domestic hydrogen acceptance, the analysis suggests that production perceptions, public trust, perceived relative advantage, safety perceptions, knowledge and awareness, and positive emotions will shape consumer support for hydrogen homes. Conversely, perceived disruptive impacts, perceived socio-economic costs, financial perceptions, and negative emotions may impede the domestic hydrogen transition. Consumer acceptance stands to significantly shape deployment prospects for hydrogen boilers and hobs, which are perceived to be somewhat advantageous to natural gas appliances from a technological and safety perspective. The study attests to the predictive benefits of adopting an integrated theoretical perspective when modelling the early stages of the innovation-decision process, while acknowledging opportunities for leveraging innovative research approaches in the future. As national hydrogen economies gain traction, adopting a neuroscience-based approach may help deepen scientific understanding regarding the neural, psychological, and emotional signatures shaping consumer perspectives towards hydrogen homes.

Abbreviations: ADV, Perceived Relative Advantage; AVE, Average variance extracted; BIC, Bayesian information criterion; BLR, Perceived Boiler Performance; CA, Cronbach Alpha; CCS, Carbon capture and storage; CMB, Common method bias; COP, Conference of the Parties; CR, Composite Reliability; C-TAM-TPB, Combined Technology Acceptance Model-Theory of Planned Behaviour; CVPAT, Cross-validated predictive ability test; DESNZ, Department for Energy Security and Net Zero; DHA, Domestic Hydrogen Acceptance; DHAM, Domestic Hydrogen Acceptance Model; DoI, Diffusion of Innovation; ECG, Electrocardiogram; FP, Financial Perceptions; fMRI, functional Magnetic Resonance Imaging; GOV, Trust in the government; HKA, Hydrogen Knowledge and Awareness; HOB, Perceived Hob Performance; HTMT, Heterotrait-monotrait; IA, Indicator Average; IMPA, Importance-performance map analysis; LM, Linear Model; LV, Latent variable; MAE, Mean absolute error; NAM, Norm Activation Model; NE, Negative Emotions; NeuroH2, Neuroscience for hydrogen systems; NeuroIS, Neuroscience for information systems; NGN, Northern Gas Networks; NRG, Trust in the energy sector; PLS-SEM, Partial least squares structural equation modelling; PDI, Perceived Disruptive Impacts; PSC, Perceived Socio-economic Costs; PE, Positive Emotions; PP, Production Perceptions; PT, Public Trust; QUAL, Trust in product and service quality; R&D, Trust in Research & Development; R², Coefficient of determination; RMSE, Root mean squared error; SETA, Sustainable Energy Technology Acceptance; SP, Safety Perceptions; SMR, Steam methane reformation; TAM, Technology Acceptance Model; TPB, Theory of Planned Behaviour; TRA, Theory of reasoned action; STEEEP, Safety-Technological-Economic-Environmental-Emotional-Perspectives; ST, Social Trust; UTAUT, Unified Theory of Acceptance and Use of Technology; UTAUT2, Unified Theory of Acceptance and Use of Technology 2; VIF, Variance inflation factor; WTA, Willingness to Adopt a Hydrogen Home.

* Corresponding author.

E-mail addresses: joel.gordon@mespom.eu, joel.gordon@iitue.lu.se (J.A. Gordon).

<https://doi.org/10.1016/j.ijhydene.2024.11.061>

Received 13 June 2024; Received in revised form 12 September 2024; Accepted 3 November 2024

Available online 14 November 2024

0360-3199/© 2024 The Authors. Published by Elsevier Ltd on behalf of Hydrogen Energy Publications LLC. This is an open access article under the CC BY license (<http://creativecommons.org/licenses/by/4.0/>).

1. Introduction

Following the emergence of seminal contributions to the field of social psychology [1–3], scholars have explicitly recognised the predictive benefits that integrated theoretical approaches can yield when modelling human decision-making and behaviour [4–9].¹ Early recognition of this advantage is well reflected in the Combined Technology Acceptance Model-Theory of Planned Behaviour (C-TAM-TPB) framework advanced by Taylor and Todd [10], which continues to gain traction among scholars after nearly three decades [11–13].² Arguably, the most emblematic theoretical contribution of this nature can be traced to the 2003 publication of Ventakesh and colleagues' [14], which inaugurated the Unified Theory of Acceptance and Use of Technology (UTAUT).

Subsequently, researchers have frequently adapted or extended the UTAUT to examine emerging phenomena [15], such as consumer attitudes towards mobile phone apps [16–18], driverless vehicles [19,20], smart home technologies [21,22], and rooftop solar PV [23,24]. Marking an improvement to its predecessor [14], the UTAUT's next iteration, UTAUT2, incorporated three additional constructs to the modelling approach. Notably, this change strengthened the in-sample predictive power of the model by 18% ($R^2 = 0.740$) and 12% ($R^2 = 0.520$) when explaining behavioural intention and technology use in relation to mobile internet [25].

In the intervening decade between UTAUT and UTAUT2, contemporaries of Ventakesh et al. [14] consolidated the premise that integrated or unified modelling approaches may better explain and predict the critical success and resistance factors of technology acceptance [26–29]. Crucially, theory development can help support more robust causal explanations and predictions, in addition to facilitating design and action via explicit policy or managerial prescriptions [30]. As a general guideline, sound theories should ensure comprehensiveness without resorting to excessive levels of complexity, which can occur when numerous constructs or moderating relationships are postulated [31], as critically discussed in Supplementary Note 1 (see SN1).

As exemplified by the Sustainable Energy Technology Acceptance (SETA) model pioneered by Huijts et al. [32] (see SN2) and reflected within recent meta-analyses [33,34], various conceptual approaches have emerged for modelling different components of energy technology acceptance [35–38]. Nevertheless, theory development in the context of the hydrogen economy remains somewhat limited [39]. To date, most regression-based models engaging with hydrogen acceptance – primarily engaging with fuelling stations and fuel cell vehicles [40,41] – have lacked explicit theoretical foundations or limited their scope to just a few variables [39,42]. Acknowledging limitations in the literature, Gordon et al. [42] posited a unified theory of domestic hydrogen acceptance, wherein perceptual antecedents of rational thought and emotional response shape consumer attitudes and behavioural intentions in the context of transitioning to a 'hydrogen home' [43].

In its totality, the unified theory advanced by Gordon and colleagues [42] draws from Roger's Diffusion of Innovation (DoI) theory [44], Schwartz's Norm Activation Model (NAM) [45], the Theory of Planned Behaviour (TPB)³ [46], and Davis' Technology Acceptance Model (TAM) [47], alongside risk perceptions literature [48,49], trust-based [50–54] and affective-based models [26,55–57], in addition to specific energy acceptance frameworks [32,58,59]. While the unified theory

presents an important juncture for understanding hydrogen acceptance [42], knowledge is ultimately advanced through the building and subsequent operationalisation of models [60]. To date, several constructs hypothesised by Gordon et al. [42] are yet to be tested as originally formulated, following an initial focus on the respective antecedents of social acceptance [61] and perceived technology adoption potential [62, 63].

In response, the conceptual innovation of this study lies with developing an integrated model of domestic hydrogen acceptance and adoption, which is grounded in the following approaches: the Domestic Hydrogen Acceptance Model (DHAM) [61]; the Safety-Technological-Economic-Environmental-Emotional-Perspectives (STEEEP) Framework [63]; and a trust-based model exploring the relationships between perceived community benefits, domestic hydrogen acceptance, and adoption willingness [64]. The novelty of the contribution involves leveraging insights from emerging theoretical foundations [64] and recent empirical contributions [65–68] to comprehensively examine interrelations between the perceptual, cognitive, and emotional antecedents shaping consumer perspectives towards hydrogen homes. To support the core research motivation, the following research questions are formulated:

- What are the critical drivers and barriers shaping domestic hydrogen acceptance?
- What are the critical drivers and barriers shaping willingness to adopt a hydrogen home before 2030?
- Does an integrated modelling approach support higher predictive capabilities?

Following this introduction, Section 2 contextualises recent developments regarding the contested transition to hydrogen homes in the UK context. Section 3 describes the research design and modelling approach, and further outlines the structure of the study. Next, Section 4 elucidates the conceptual approach, while Section 5 develops hypotheses to test the proposed framework. Subsequently, Section 6 relays and discusses findings from partial least squares structural equation modelling (PLS-SEM) and importance-performance map analysis (IMP). Finally, Section 7 concludes by acknowledging the limitations of the study, highlighting opportunities for further research, and emphasising critical lessons for steering the domestic hydrogen transition towards a socially acceptable trajectory.

2. The contested transition to hydrogen homes

Historically, rapid energy transitions for the residential sector have proved feasible in select cases [69], as witnessed via the deployment of heat pumps in Scandinavian countries [70,71], district heating in Denmark [69], and solar thermal systems in China [72]. Of most relevance to the context of this study, the UK achieved a rapid national energy transition between 1960–1977⁴ [69] by switching from manufactured 'town gas'⁵ to natural gas [73,74]. However, as scholars continue to debate the temporal dynamics of the clean energy transition [75–77], public opposition is but one of several socio-technical barriers [78] that may counteract decarbonisation efforts [79–81]. As reflected across different national contexts [82–84], social resistance can substantially undermine ambitions to scale up low-carbon energy technologies [85–87], casting doubt over the feasibility of net-zero targets in countries such as the UK [88–90].

¹ Parts of the manuscript including the introduction are adapted from the lead author's PhD dissertation [349].

² Generally, the early 2000s marked the proliferation of 'decomposed' models of the TPB and extended versions of the TAM, which integrated constructs from Diffusion of Innovation (DoI) Theory such as perceived technology attributes [350–352].

³ Based on the Theory of Reasoned Action (TRA) which Ajzen developed alongside Fishbein [2].

⁴ Scholars acknowledge and debate the difficulty of tracing the formative phase of energy transitions when formalising national case studies [31,32]. For example, Arapostathis et al. [74] discuss the transition from town gas to natural gas for the period 1948–1977.

⁵ Made up of methane (CH₄), carbon monoxide (CO) and up to 50% hydrogen [30].

Although a relatively nascent development, domestic hydrogen presents an emblematic case of a contested energy transition [91–93], which partly captures historical developments regarding hydrogen-based energy futures [94–96]. Mapping recent developments in the German context, Kern et al. [97] discuss how developing a national hydrogen economy will involve navigating multiple contested pathways regarding both production pathways and technology applications. Moreover, leading political parties may hold diametrically opposed views over the future of heat pumps and hydrogen, which has been reflected in emerging media narratives in Germany [97]. Reviewing global developments, Vezzoni [98] further unpacks “contested aspects of hydrogen off-take, transportation, infrastructural investments, and production processes,” calling for stronger participatory processes in the energy transition.

In August 2021 the UK government released its Hydrogen Strategy [99] ahead of the Conference of the Parties in Glasgow (COP26). Following recognition of a potential role for low-carbon hydrogen in UK buildings since the mid-2010s [100,101], the strategy included a focus on domestic hydrogen [99]. Specifically, it was announced that a policy decision on hydrogen homes should be taken in 2026 [99], as further consolidated within the Heat and Buildings Strategy in October 2021 [102]. Notably, following the destabilising effects of Russia’s invasion of Ukraine [103,104], the British Energy Security Strategy increased the hydrogen production from 5 GW to 10 GW [105], in conjunction with advancing plans for hydrogen village trials in industrial locations [106–108].

Despite initial signs of momentum, the socio-political feasibility of hydrogen homes currently hangs in the balance, following the recent cancellation of anticipated village trials [92] for the North of England [109,110] and growing policy support for electrifying the UK housing stock [111]. Nevertheless, in its latest update on hydrogen heating, the Department for Energy Security and Net Zero (DESNZ) [112] affirmed that a policy decision would still be taken in 2026, while drawing more directly on international evidence from countries such as the Netherlands and Germany, as national research continues:

“Unlike other technologies, 100% hydrogen for heating is not yet an established technology. Further work is required to understand the feasibility, costs, and convenience of transporting 100% hydrogen in the gas grid and using hydrogen for heating and cooking” [112].

Mirroring the motivation of this study, the DESNZ update cited the value of consumer research gathered by Northern Gas Networks (NGN) in the context of the planned trial for Redcar in North Yorkshire [112]. Additionally, first-hand evidence of the consumer experience of hydrogen homes in the UK may yet be provided through the prospective H100 Fife neighbourhood trial in East-central Scotland [112]. However, supply-chain and procurement challenges, alongside a potential lack of consumer buy-in continue to challenge the timeline and feasibility of the Fife trial [113], while the environmental and safety credentials of domestic hydrogen remain subject to scrutiny [114,115].

Recent developments in the UK suggest any prospective pathway to deploying hydrogen homes is likely to incur a degree of consumer resistance, as reflected in the bottom half of Fig. 1. In parallel, both the heat pump transition and switch to smart meters have faced and continue to confront significant barriers to social acceptance [116–119], which has delayed progress on residential decarbonisation. Fig. 1 cautions that transitioning to hydrogen homes may fail to prove a viable near-term policy pathway. At the same time, the historical record reflects the dynamic nature of social acceptance [120,121], which is perhaps best exemplified by diverging support for nuclear power across parts of Europe [122–125]. To an extent, domestic hydrogen echoes some of the characteristics of nuclear power in presenting a contested and costly technology pathway [126], which will be largely determined by techno-economic, political, and socio-technical capacities at the national level [127].

3. Material and methods

3.1. Questionnaire design and data collection

This study employs an online survey to examine how UK consumers perceive the prospect of transitioning to a hydrogen home before 2030. The survey instruments (see SN3) were supported by findings from online focus groups [43,128,129] and extensive literature review on the subject matter [42,78,120], as reflected in Table 1. Piloting for the survey took place over the summer of 2022, supported by additional inputs from hydrogen experts and social scientists. Once content and face validity had been firmly established [61,130] data collection commenced in October 2022. The survey closed towards the end of 2022 with more than 2000 responses, leading to a sizeable final sample after data cleaning was completed ($N = 1845$).⁶

3.2. Characteristics of the survey sample

The sample proved largely nationally representative of the UK population, while entailing four distinct consumer sub-groups demarcated by their socio-economic profile, and levels of engagement in technology and the environment (see SN4), as further detailed in the context of multigroup analysis [62,63]. This configuration helps support national representativeness in a more nuanced way (i.e. compared to relying exclusively on socio-demographic variables), since early adoption potential and environmental attitude are embedded into the sample characteristics [165].

At the aggregate level, just over one-third of respondents are outright property owners, while close to two-thirds are mortgage owners, with all participants dwelling in homes reliant on natural gas heating and cooking. Additionally, the filtering approach targets respondents that are liable to be directly affected by the domestic hydrogen transition through two conditions: all respondents reported an at least moderate level of financial participation in purchasing decisions, while assigning at least moderate importance to deciding between available heating and cooking technologies. Accordingly, the sampling approach internalises the need to account for agency and choice when examining energy technology acceptance [166]. Additional details of the sample breakdown are provided in Supplementary Note 5 (see SN5).

3.3. Data analysis

3.3.1. Partial least squares structural equation modelling

Given that domestic hydrogen presents an emerging technology, this study utilises PLS-SEM to advance theoretical and empirical insights in a nascent research context [167–169]. PLS-SEM supports a predictive-oriented modelling approach [170,171] by minimising the unexplained variance of predictors [172]. The method has gained increasing popularity across the social sciences for supporting theory development and prediction [170,173] in areas such as information technology and business management [174–177]. Increasingly, energy transition scholars have leveraged PLS-SEM to examine multiple areas [43], such as smart home technologies [178–180], solar PV [181,182], energy-efficient heating appliances [183], and hydrogen fuel cell vehicles [140,152,184].

This study applied SmartPLS 4.1 software [185] to test the predictive capabilities of an integrated model of domestic hydrogen acceptance and adoption intention. Following conventions in the literature, the two-stage approach is implemented by firstly validating the measurement (or outer) model, ahead of testing the path relationships composing the structural (or inner) model [186]. To uphold methodological rigour, this study adheres to up-to-date guidelines when

⁶ i.e. removal of straight-lining responses, fast responses, and other irregularities which impeded the integrity of the data.

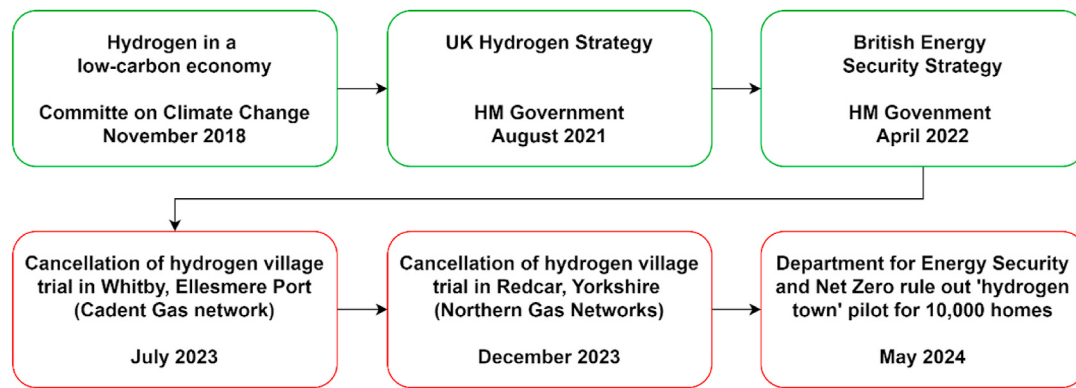


Fig. 1. Overview of key policy developments shaping the domestic hydrogen transition.

justifying the decision to use PLS-SEM [177,187]. Accordingly, validity checks for sample size and statistical significance levels are firstly performed, in addition to testing for common method bias (CMB), skewness, and kurtosis [188,189].

The robustness of the sample size was verified using G-Power software analysis [190,191] to calculate model-specific estimates for effect size [192]. Given the parameters of the proposed model, the sample size proved more than sufficient for detecting a small effect size ($f^2 = 0.02$) at a 95% significance level ($p < 0.05$), as reported in SN6. Additionally, CMB was tested using Harman's single factor test [193], which returned a variance of 26.97%, substantially below the guideline of 50% (see SN7). Lastly, data integrity was further supported since results for skewness and kurtosis fell comfortably within the suggested threshold of ± 1 (see SN8).

3.3.2. Importance-performance map analysis

To derive further insights from PLS-SEM, importance-performance map analysis (IMPA) [194,195] is undertaken at the construct level for domestic hydrogen acceptance, and at the construct and indicator level for willingness to adopt a hydrogen home before 2030. Within an X–Y plot, IMPA provides a means to compare importance (i.e. unstandardised total effects) and performance (i.e. latent variable scores rescaled from 0 to 100) [194] to help inform strategic decision-making [196,197]. When interpreting results, constructs positioned at the bottom right quadrant represent the foremost area of strategic value [194,198]. Constructs within this quadrant display a high level of importance but significant scope for improving their contribution (i.e. performance) towards realising the target outcome [199–202].

3.3.3. Summary of data analysis procedure

Fig. 2 outlines the structure of the study by visualising the research steps and data analysis techniques. Following the description of the conceptual framework in Section 4, Section 5 develops hypotheses for testing the integrated model, which is described and visualised in Section 6. Subsequently, Section 6.1 presents the descriptive results at the indicator level, ahead of assessing the measurement and structural models in Sections 6.2 and 6.3, respectively. Following IMPA in Section 6.4, the predictive capabilities of model are reported in Section 6.5. Finally, Section 6.6 crystallises the analysis through a comparative assessment of modelling results on the acceptance and adoption dynamics of hydrogen homes.

4. Conceptual framework

Following increased recognition that cognitive, psychological, and emotional processes are deeply intertwined in energy-related decisions and behaviours [203], integrated approaches for modelling residential energy acceptance have emerged in the literature [204–206]. The foundations of integrated models of domestic energy acceptance [38,

207] can be traced to the UTAUT [14] and its derivatives [25,208], as discussed in Section 1 and SN2. The energy transitions literature has since evolved to reflect a more comprehensive focus on socio-psychological, emotional, behavioural, cultural, ethical, and contextual factors [207,209–211]. Critically, by adopting a more integrated perspective [26,212,213] researchers can enhance the explanatory and predictive power of their models [14,22,205].

While early efforts have been taken to embed an interdisciplinary research perspective into hydrogen acceptance studies [61,133], the need for innovative and sustained exploration has been duly acknowledged [39,42]. In response, the proposed model examines the direct effects of four exogenous constructs (production perceptions, safety perceptions, perceived socio-economic costs and perceived disruptive impacts) and two higher-order constructs (public trust and perceived relative advantage) on domestic hydrogen acceptance, which in turn predicts willingness to adopt a hydrogen home before 2030. Additionally, adoption willingness is predicted by four exogenous constructs (hydrogen knowledge and awareness, financial perceptions, positive emotions, and negative emotions), as depicted in Fig. 3.

Through this approach, the integrated model departs from its predecessors in a fundamental way, namely, domestic hydrogen acceptance consists of three indicators measuring support for hydrogen homes at the household, community, and socio-political level, and three indicators measuring perceived economic, social, and environmental benefits at the local level. Following exemplars of developing new measurement items [214,215], this line of thinking has been previously applied when constructing a hybrid construct for perceived adoption potential [63], but is yet to be incorporated when operationalising social acceptance as an endogenous construct.⁷ Accordingly, the dimension of community acceptance [58,216] is explicitly represented within this study, which is critical given the spatial dynamics of developing hydrogen homes [120] and recent failure to secure local support for village trials in the North of England [109,110].

In total, excluding the lower-order constructs composing public trust and perceived relative advantage, twelve constructs comprise the integrated model (eight exogenous and four endogenous). The constructs are measured reflectively since corresponding indicators are correlated and do not form the construct [217,218]. To increase model parsimony and predictive power, public trust and perceived relative advantage are operationalised as reflective-formative constructs [219].⁸ As a result, the proposed framework answers the call for theoretical rigour and

⁷ Exogenous constructs are independent variables (i.e. arrows pointing away from the construct) whereas endogenous constructs are dependent variables (but can also function as predictors as is the case with domestic hydrogen acceptance in the presented model).

⁸ i.e. all indicator items are measured reflectively while the lower-order constructs point towards the higher-order constructs [353].

Table 1

Summary of questionnaire framing, construct items, and supporting literature.

Construct and scale	Indicators and question framing	Supporting literature
Public Trust (PT) (HOC) ^a 11-point Trust in government	➤ In supporting a cost-effective, efficient, and fair transition to hydrogen homes	[43,131–135]
Trust in the energy sector	<ul style="list-style-type: none"> • GOV1: Central government • GOV2: Regional authorities • GOV3: Local councils • NRG1: Fuel/gas supply companies • NRG2: Electricity and/or gas suppliers • NRG3: Renewable energy producers 	
Trust in product and service quality	<ul style="list-style-type: none"> • QUAL1: Trades bodies/associations • QUAL2: Boiler manufacturers • QUAL3: Gas engineers and technicians 	
Trust in research & development	<ul style="list-style-type: none"> • R&D1: Non-governmental organisations • R&D2: Universities • R&D3: Other research institutes and organisations 	
Social trust	<ul style="list-style-type: none"> • ST1: Gas distribution network operators • ST2: Financial institutions • ST3: Office of gas and electricity markets • ST4: Media 	
Production perceptions (PP) 11-point	➤ <i>Support for hydrogen production pathways over different time-horizons</i> <ul style="list-style-type: none"> • PP1: Blue hydrogen up to 2030 • PP2: Blue hydrogen after 2030 • PP3: Green hydrogen up to 2030 • PP4: Green hydrogen after 2030 • PP5: The twin-track production approach 	[65,134–138]
Safety perceptions (SP) 11-point	➤ <i>Compared to natural gas</i> <ul style="list-style-type: none"> • SP1: Hydrogen boilers • SP2: Hydrogen hobs • SP3: Hydrogen pipeline transport • SP4: Underground hydrogen storage • SP5: Overall safety level 	[134,135,139–145]
Perceived disruptive Impacts (PDI) 5-point	➤ <i>Concern about impacts during the hydrogen switchover period</i> <ul style="list-style-type: none"> • PDI1: Noise, traffic, and inconvenience during the switchover • PD2: Temporary disconnection from the gas grid • PDI3: Visits from gas engineers and technicians 	[43,132,134,135,146]
Perceived socio-economic costs (PSC) 5-point	➤ <i>Negative macro-economic risks</i> <ul style="list-style-type: none"> • PSC1: Negative impact on UK energy security • PSC2: Higher levels of fuel poverty across the UK 	[39,43,68,144,147,148]
Perceived Relative Advantage (ADV) HOC ^a 11-point Perceived boiler performance	➤ Perceived performance advantage compared to a natural gas boiler or a natural gas hob	[134,145,149–151]
Perceived hob performance	<ul style="list-style-type: none"> • BLR1: Higher level of thermal comfort • BLR2: Higher energy efficiency • BLR3: Smarter heating system • HOB1: More efficient performance • HOB2: Better cooking control • HOB3: Smarter cooking system 	
Domestic hydrogen acceptance (DHA) 11-point	➤ <i>Socio-political, community, and household-level acceptance, and perceived community benefits</i> <ul style="list-style-type: none"> • DHA1: Hydrogen becoming a critical part of the UK's energy future • DHA2: Hydrogen replacing natural gas in your local area before 2030 • DHA3: Switching your home to both hydrogen heating and cooking before 2030 • DHA4: Economic benefits such as job opportunities and income security • DHA5: Social benefits such as reduced level of energy poverty and improved health • DHA6: Environmental benefits such as lower carbon emissions and better air quality 	[43,99,132,152–154]
Hydrogen knowledge and awareness (HKA) 5-point	➤ <i>Subjective Knowledge of hydrogen fuel and awareness of low-carbon and hydrogen energy</i> <ul style="list-style-type: none"> • HKA1: Subjective knowledge • HKA2: Awareness of low-carbon residential energy technology • HKA3: Awareness of the UK hydrogen strategy • HKA4: Awareness of hydrogen homes 	[133,135,138,139,141,152,155]
Financial perceptions (FP) 5-point	➤ <i>Expectations compared to natural gas</i> <ul style="list-style-type: none"> • FP1: Purchasing a hydrogen boiler • FP2: Purchasing a hydrogen hob • FP3: Energy bills 	[134,145,149–151,156–158]
Positive emotions (PE) 5-Point	➤ <i>Feelings about using a hydrogen boiler and hob within your home</i> <ul style="list-style-type: none"> • PE1: Satisfied • PE2: Calm • PE3: Confident • PE4: Optimistic 	[140,155,159–162]
Negative emotions (NE) 5-point	➤ <i>Feelings about using a hydrogen boiler and hob within your home</i> <ul style="list-style-type: none"> • NE1: Discontent 	[140,155,159–162]

(continued on next page)

Table 1 (continued)

Construct and scale	Indicators and question framing	Supporting literature
	<ul style="list-style-type: none">• NE2: Worried• NE3: Fearful• NE4: Pessimistic	
Willingness to adopt a hydrogen home (WTA) 5-point	<ul style="list-style-type: none">➤ Before the year 2030• WTA1: Hydrogen boiler• WTA2: Hydrogen hob• WTA3: Hydrogen home	[39,120,163,164]

^a Higher-order construct.

multi-dimensional integration in hydrogen acceptance studies [39]. Foremost, the combined model leverages the building blocks of the unified theory of domestic hydrogen acceptance [42] to examine perceptual, cognitive, and emotional factors shaping consumer perspectives of hydrogen homes, culminating in a mid-range theory that is context-specific yet firmly rooted in seminal literature [9].

5. Hypotheses development

5.1. Public trust in the domestic hydrogen transition

Energy transitions researchers have engaged with the multi-dimensional nature of public trust across a range of contexts and technology cases [220], such as onshore and offshore wind power [221], marine energy futures [222], nuclear power [223] and nuclear fusion [224], among other examples [225–227]. The dynamics of public trust have also attracted the attention of hydrogen acceptance scholars, following early engagement from Huijts et al. [228] in the Dutch context. Subsequently, several studies conducted in Germany have included trust metrics in their modelling approaches [153,229,230], with researchers in Australia [134,149,231] and the UK extending the evidence base [43,137,158].

Although a growing literature has steadily emerged spanning different country contexts and hydrogen applications [39], Gordon et al. [42,64] argue that trust-related research on energy acceptance remains far from saturated, motivating the need for high-level conceptual and empirical engagement. In response, a trust-based model of domestic hydrogen acceptance and adoption intention has been developed in

supporting research [64], which is leveraged in this analysis. The following hypotheses are developed to validate the antecedents of public trust in hydrogen homes:

- H1a.** Trust in the government will significantly and positively affect public trust in the domestic hydrogen transition.
- H1b.** Trust in the energy sector will significantly and positively affect public trust in the domestic hydrogen transition.
- H1c.** Trust in product and service quality will significantly and positively affect public trust in the domestic hydrogen transition.
- H1d.** Trust in research and development will significantly and positively affect public trust in the domestic hydrogen transition.
- H1e.** Social trust will significantly and positively affect public trust in the domestic hydrogen transition.

Subsequently, the interactions between public trust and domestic hydrogen acceptance is explored in H2a. Accordingly, the proposed model reflects similar trust-acceptability models [232], which have been applied in contexts such as carbon capture and storage (CCS) [233,234] and hydrogen-powered transportation in the Netherlands [131,228], electricity generation sources in Chile [235] and South Korea [236], and nuclear power in Switzerland [237] and China [238]. In response, hypotheses are also formulated to test whether public trust effectively mediates the relationship between its lower-order constructs and domestic hydrogen acceptance, as posited in H2b–H2f.

- H2a.** Public trust in key stakeholders and actors will significantly and

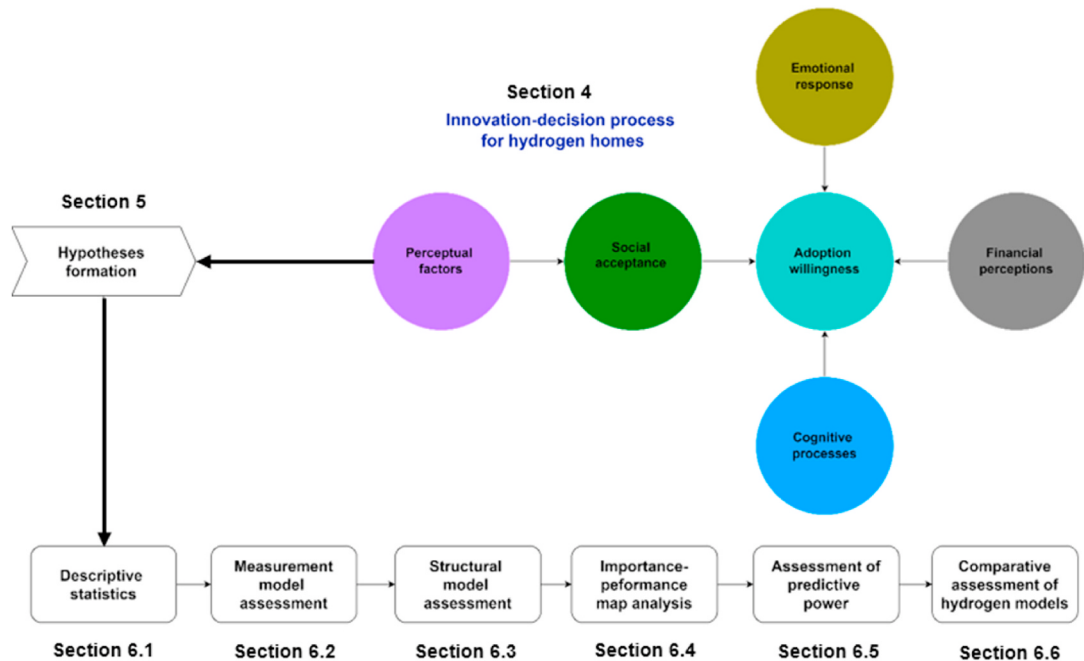


Fig. 2. Research procedure and data analysis methods.



Fig. 3. Conceptual framework for examining the innovation-decision process for hydrogen homes.

positively affect domestic hydrogen acceptance.

H2b. Public trust in key stakeholders and actors will significantly and positively mediate the relationship between trust in the government and domestic hydrogen acceptance.

H2c. Public trust in key stakeholders and actors will significantly and positively mediate the relationship between trust in the energy sector and domestic hydrogen acceptance.

H2d. Public trust in key stakeholders and actors will significantly and positively mediate the relationship between trust in product and service quality and domestic hydrogen acceptance.

H2e. Public trust in key stakeholders and actors will significantly and positively mediate the relationship between trust in research and development and domestic hydrogen acceptance.

H2f. Public trust in key stakeholders and actors will significantly and positively mediate the relationship between social trust and domestic

hydrogen acceptance.

5.2. Perceptions of hydrogen production pathways

Prior mixed-methods research conducted in the UK context [129] highlights the likelihood that public perceptions of hydrogen production pathways will influence social acceptance. To date, results suggest more support for a ‘green’ production pathway [61] utilising “electrolytic hydrogen predominantly powered by renewables” [99], as opposed to a ‘blue’ pathway reliant on steam methane reformation (SMR) and CCS [239]. While this preference is largely reflected in the European [65, 240] and Australian contexts [150], survey results from Japan observe less comparative support for green hydrogen when cost considerations trump environmental concerns [66]. In response, the subsequent hypothesis examines how production perceptions will shape public support vis-à-vis the UK’s ‘twin-track’ approach [99], which aims for at least 50% green production by 2030 [105]:

H3. Production perceptions will significantly and positively affect domestic hydrogen acceptance.

5.3. Hydrogen safety perceptions

The initial feasibility of launching hydrogen homes in proximity to industrial clusters will rest firmly on safety-related parameters [241]. Consequently, hydrogen pipelines and infrastructure must be non-hazardous, and the fuel must prove safe for transporting and storing [242]. The current scientific consensus is that hydrogen has a comparable risk profile to natural gas and gasoline [243,244]. Against this backdrop, safety perceptions of hydrogen are examined in comparison to natural gas, positing a positive impact on social acceptance in line with prior research findings [61,130]:

H4. Safety perceptions will significantly and positively affect domestic hydrogen acceptance.

5.4. Perceived disruptive impacts of the hydrogen switchover

Switching parts of the national gas grid to hydrogen will entail a degree of short-term disruption to consumers at street level and within their properties [164]. Nevertheless, ‘soft’ risks associated with increased traffic, noise, and inconvenience may arouse significant concerns at both the community and individual level [61,156], especially if the switchover period exceeds three to four days [43,146]. The perceived disruptive impacts of converting to a hydrogen home will be heightened and may prove intolerable among vulnerable consumers such as the elderly and fuel poor [43,146]. In response, the following hypothesis is developed to capture these important dynamics:

H5. The perceived disruptive impacts of the hydrogen switchover will significantly and negatively affect domestic hydrogen acceptance.

5.5. Perceived socio-economics costs of the domestic hydrogen transition

The perceived socio-economic costs of the domestic hydrogen transition will rest on how consumers anticipate macro-level impacts on energy security and fuel poverty [61]. One study conducted in the North of England suggested mostly neutral perceptions concerning macro-economic impacts [144]. However, the regional survey was conducted before the COVID-19 pandemic [245] and outbreak of war in Ukraine [246], which have contributed towards an unprecedented period of political and economic instability [247,248], aggravating fuel poverty in the UK context [249]. In view of the ensuing energy crisis [43] and its cascading global implications [104], the following hypothesis is posited:

H6. The perceived socio-economic costs of transitioning to hydrogen homes will significantly and negatively affect domestic hydrogen acceptance.

5.6. Perceived relative advantage of hydrogen homes

The UK Hydrogen Strategy [99] cites the importance of establishing a robust evidence base ahead of a policy decision on domestic hydrogen in 2026, which includes gauging how consumers perceive and experience hydrogen heating and cooking relative to other low-carbon solutions [112]. Relatedly, studies examining low-carbon energy technology acceptance in the residential context [250–252] reflect the importance of perceived relative advantage [44] in guiding consumer decision-making. The rationale is that early adopters will expect hydrogen boilers and hobs to perform equally well as, or to otherwise surpass, the incumbent technology [42].

Although the deployment of hydrogen homes remains hypothetical, there appears to be a general belief among the UK public that hydrogen-fuelled technologies would outperform natural gas boilers and hobs in

terms of efficiency and smartness [128]. However, scholars such as Scott and Powells [145] have also documented that consumers may have a more explicit preference for hydrogen heating due to less immediate impacts on the lived experience of residential energy consumption compared to hydrogen cooking. Following recent consumer-oriented research on domestic hydrogen [130], this analysis examines the connection between technology perceptions for hydrogen heating and cooking, perceived relative advantage, and domestic hydrogen acceptance through a series of hypotheses:

H7a. The perceived performance of hydrogen boilers will significantly and positively affect the perceived relative advantage of hydrogen homes.

H7b. The perceived performance of hydrogen hobs will significantly and positively affect the perceived relative advantage of hydrogen homes.

H7c. The perceived relative advantage of hydrogen homes will significantly and positively affect domestic hydrogen acceptance.

H7d. The perceived relative advantage of hydrogen homes will significantly and positively mediate the relationship between the perceived performance of hydrogen boilers and domestic hydrogen acceptance.

H7e. The perceived relative advantage of hydrogen homes will significantly and positively mediate the relationship between the perceived performance of hydrogen hobs and domestic hydrogen acceptance.

5.7. Social acceptance and adoption intention

Following Ajzen’s [46] theory of planned behaviour (TPB) and its forerunner, the theory of reasoned action (TRA) [2], the link between attitude and behavioural intention has been well-established in seminal technology acceptance models [14,253]. This interplay has been acknowledged and explored by energy scholars for more than a decade [32], lending support to the notion that acceptance predicts adoption intention and subsequent decision-making [182,183,238]. At the same time, researchers have documented the underlying prevalence of an intention-behaviour gap across different contexts [254,255], which may undermine actual low-carbon energy adoption [256,257]. This study sets out to quantify the strength of the relationship between domestic hydrogen acceptance and adoption willingness, in addition to testing the mediating role of domestic hydrogen acceptance within the integrated model:

H8a. Domestic hydrogen acceptance will significantly and positively affect consumer willingness to adopt a hydrogen home before 2030.

H8b. Domestic hydrogen acceptance will significantly and positively mediate the relationship between public trust and willingness to adopt a hydrogen home before 2030.

H8c. Domestic hydrogen acceptance will significantly and positively mediate the relationship between production perceptions and willingness to adopt a hydrogen home before 2030.

H8d. Domestic hydrogen acceptance will significantly and positively mediate the relationship between safety perceptions and willingness to adopt a hydrogen home before 2030.

H8e. Domestic hydrogen acceptance will significantly and negatively mediate the relationship between perceived disruptive impacts and willingness to adopt a hydrogen home before 2030.

H8f. Domestic hydrogen acceptance will significantly and negatively mediate the relationship between perceived socio-economic impacts and willingness to adopt a hydrogen home before 2030.

H8g. Domestic hydrogen acceptance will significantly and positively

mediate the relationship between perceived relative advantage and willingness to adopt a hydrogen home before 2030.

5.8. Hydrogen knowledge and awareness

In accordance with DoI Theory [44], knowledge and awareness mark the initial stage of the innovation-decision process, ahead of persuasion, decision, implementation, and confirmation (see Fig. 1 in Ref. [63]). Since hydrogen homes remain at the pre-deployment stage [258], consumers are yet to experience associated technologies for heating and cooking [146]. This status quo is reflected through low levels of domestic hydrogen awareness both in the UK [259] and internationally [134,260]. As a result, awareness of hydrogen boilers lags other sustainable heating technologies [259], which may partially explain higher levels of willingness to switch to a heat pump or solar heating across the UK, Germany, Italy, Spain, and Sweden [261].

Prior research suggests knowledge and awareness will increase underlying consumer support and adoption prospects for hydrogen homes [165], although a non-significant direct effect on domestic hydrogen acceptance was recorded in prior research [61]. To address the extant research gap, this analysis explores the relationship between cognitive processes and adoption willingness by integrating hydrogen knowledge and awareness into a single construct:

H9. Knowledge and awareness of hydrogen will significantly and positively affect consumer willingness to adopt a hydrogen home before 2030.

5.9. Financial perceptions of hydrogen homes

Financial factors will invariably shape consumer decision-making when choosing between low-carbon technologies for the home [261] such as hydrogen boilers and heat pumps [262]. Moreover, financial considerations become increasingly important as consumers progress along the innovation-decision process [263,264]. Survey research

indicates that around 45% of the UK population may be worried about the potential costs of installing a low-carbon heating system, while this number drops to approximately 25% when considering potential running costs [265]. In the context of transitioning to hydrogen homes, evidence suggests purchasing costs could pose the main short-term bottleneck to technology adoption [156,266]. Engaging with deprived households in the North of England, Scott and Powells [151] also identified affordability as the primary barrier to consumer acceptance, with 77% of respondents citing inability or unwillingness to pay for higher energy bills [158]. The following hypothesis is formulated to reflect dynamics underpinning financial factors at the household level, which may induce rational decision-making on the part of consumers [42]:

H10. Financial perceptions regarding the purchasing and running costs of hydrogen boilers and hobs will significantly and negatively affect consumer willingness to adopt a hydrogen home before 2030.

5.10. Positive and negative emotions

Emotions critically shape consumer perspectives towards emerging energy technologies [267,268], which has been increasingly recognised by sustainability scholars in recent years [159,162,269] especially in the context of community-level projects [270–273]. Notably, researchers have developed affective-based models to advance understanding of emotional response to energy projects and technologies [161,162,274, 275], which may fall across a wide spectrum of feelings such as hope, optimism, indifference, scepticism, and pessimism [165]. For example, in the context of hydrogen-related safety concerns and risk perceptions, negative imagery and emotions such as fear and dread may prove pervasive [131,142,276]. Alternatively, feelings of pride and gratitude may emerge among citizens of pioneering hydrogen energy communities [155]. Positive emotions may reflect a shared sentiment that hydrogen represents a fuel of the future [165,277], which is largely mirrored within the scientific community [278]. Accordingly, the

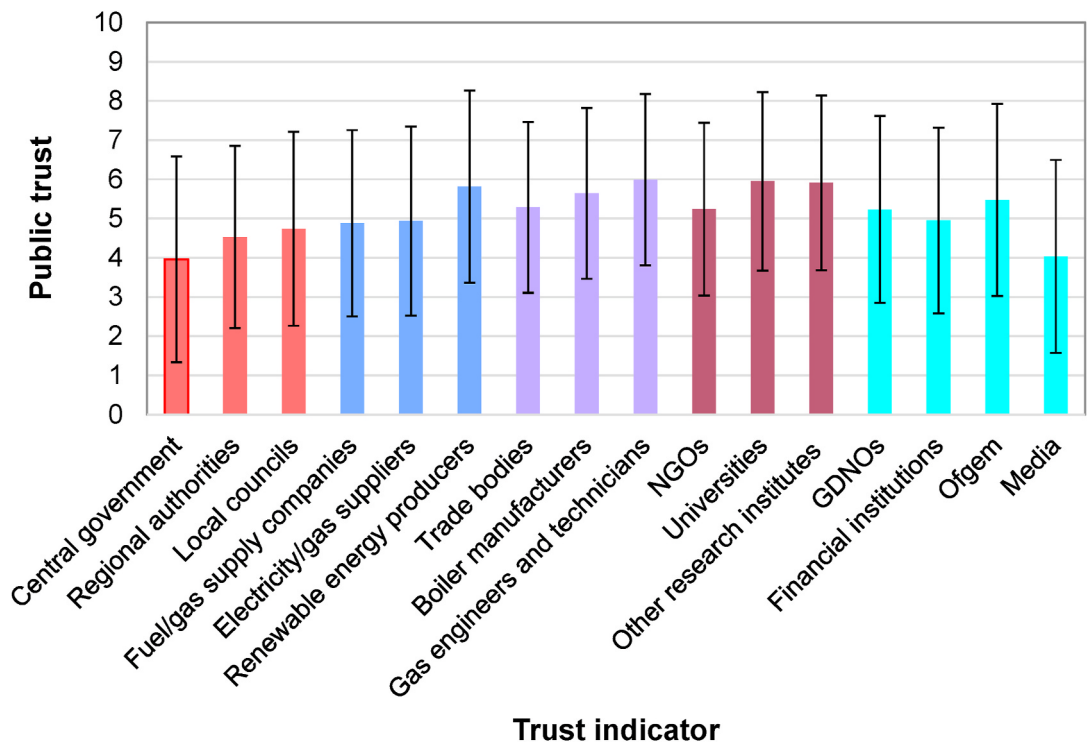


Fig. 4a. Mean score for indicators predicting public trust in the domestic hydrogen transition. Salmon = Trust in the government (GOV); Indigo = Trust in the energy sector (NRG); Mauve = Trust in product and service quality (QUAL); Grape = Trust in R&D; Turquoise = Social trust (ST).

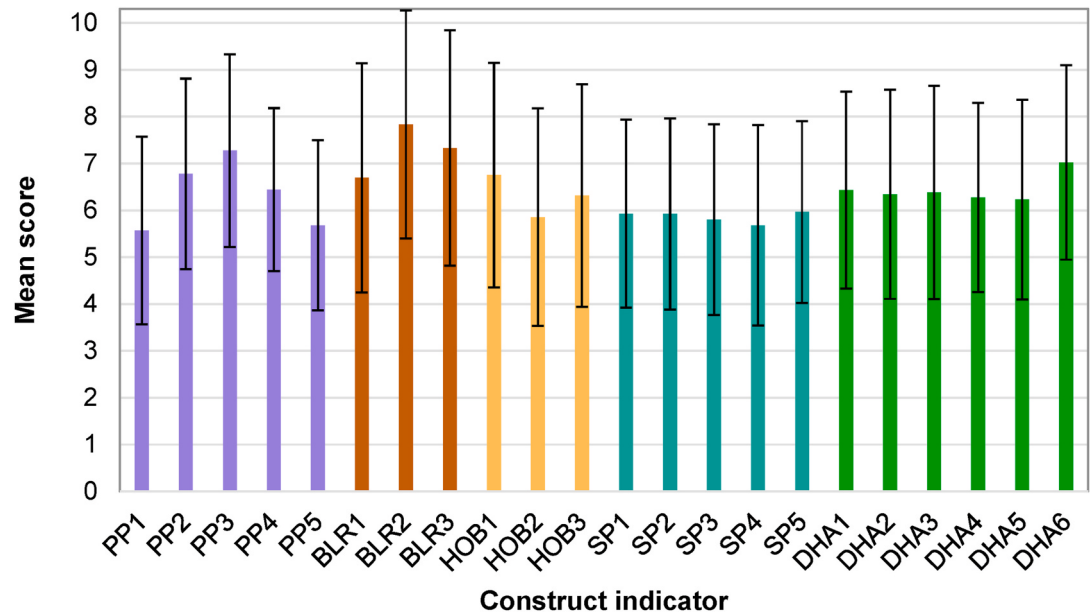


Fig. 4b. Constructs evaluated using an eleven-point Likert scale.
Purple = Production Perceptions (PP); Brown = Perceived Boiler Performance (BLR); Apricot = Perceived Hob Performance (HOB); Emerald = Safety Perceptions (SP); Green = Domestic Hydrogen Acceptance (DHA). (For interpretation of the references to colour in this figure legend, the reader is referred to the Web version of this article.)

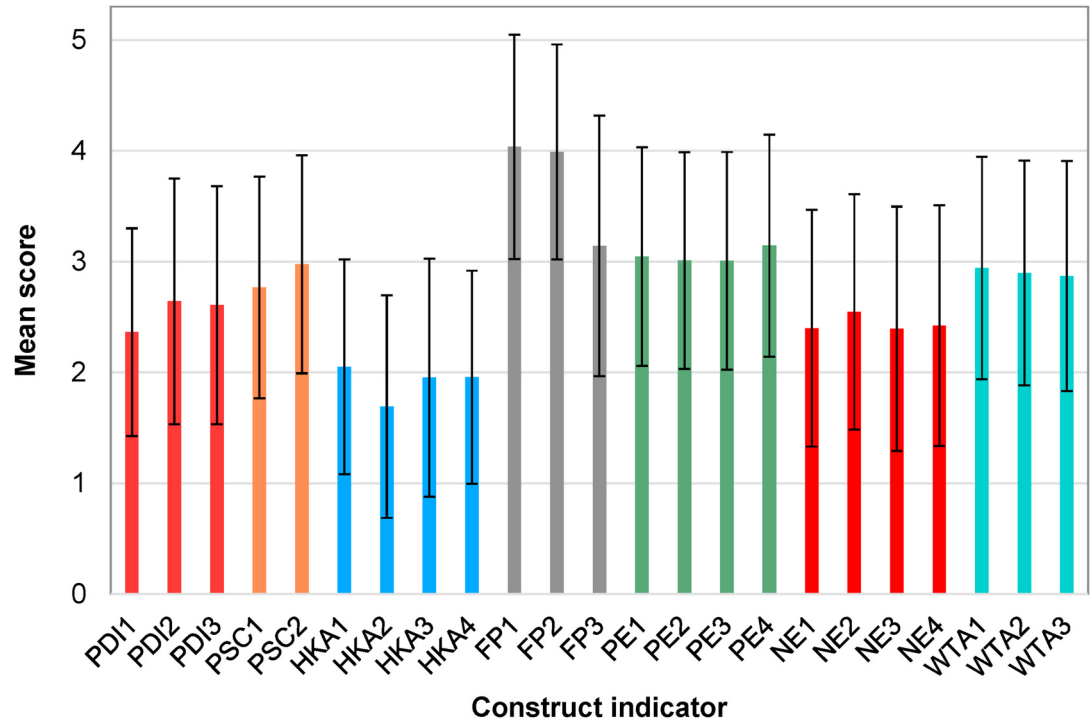


Fig. 4c. Constructs evaluated using a five-point Likert scale.
Ruby red = Perceived Disruptive Impacts (PDI); Orange = Perceived Socio-economic Costs (PSC); Blue – Hydrogen Knowledge and Awareness; Grey = Financial Perceptions; Lime = Positive Emotions (PE); Red = Negative Emotions; Teal = Willingness to Adopt Domestic Hydrogen (WTA). (For interpretation of the references to colour in this figure legend, the reader is referred to the Web version of this article.)

following hypotheses are tested to complete the analysis:

H11a. Feelings of satisfaction, calm, confidence, and optimism will significantly and positively affect consumer willingness to adopt a hydrogen home before 2030.

H11b. Feelings of discontent, worry, fear, and pessimism will significantly and negatively affect consumer willingness to adopt a hydrogen

home before 2030.

6. Results and discussion

6.1. Descriptive statistics

Ahead of testing the conceptual framework via PLS-SEM, a summary

Table 2
Assessment of construct reliability, convergent validity, and multicollinearity.

Construct	CA	CR (ρ_A)	CR (ρ_C)	AVE	VIF
Trust in Government ^a	0.889	0.893	0.932	0.819	2.369
Trust in the Energy Sector ^a	0.887	0.890	0.931	0.818	3.645
Trust in Product and Service Quality ^a	0.862	0.863	0.916	0.784	2.784
Trust in Research & Development ^a	0.832	0.833	0.899	0.749	1.978
Social trust ^a	0.842	0.846	0.894	0.678	4.853
Public trust ^b	0.916	0.918	0.937	0.749 ^c	1.466
Production Perceptions	0.816	0.844	0.870	0.578	1.385
Safety Perceptions	0.918	0.920	0.939	0.754	1.487
Perceived Disruptive Impacts	0.758	0.815	0.859	0.673	1.112
Perceived Socio-economic Costs	0.730	0.730	0.881	0.788 ^c	1.192
Perceived Boiler performance ^a	0.708	0.711	0.837	0.632	1.590
Perceived Hob performance ^a	0.822	0.824	0.894	0.738	1.590
Perceived Relative advantage ^b	0.757	0.757	0.892	0.805	1.263
Domestic H2 Acceptance	0.898	0.907	0.922	0.665	1.634
H2 Knowledge and Awareness	0.816	0.827	0.877	0.641	1.127
Financial Perceptions	0.732	0.726	0.850	0.655	1.046
Positive Emotions	0.881	0.883	0.918	0.737	1.560
Negative Emotions	0.869	0.916	0.906	0.708	1.163
Willingness to Adopt H2 Home	0.934	0.934	0.958	0.883	n/a

^a Lower-order construct.

^b Higher-order construct: validated via the disjoint two-stage approach.

^c Since PSC has two indicators, the AVE is larger than 0.50 by default.

analysis of descriptive statistics is carried out to support the investigation, as further detailed in Supplementary Note 9 (see SN9). Taken together, the sub-constructs of public trust account for 16 indicators (see Fig. 4a), which were measured using an 11-point scale and returned a moderate average ($M = 5.16$). By contrast, the mean score for perceived relative advantage (see Fig. 4b), as derived from six selected indicators, proved considerably higher ($M = 6.80$), suggesting relatively positive perceptions of hydrogen appliances from a technological perspective. Similarly, respondents are somewhat supportive of hydrogen production, but clearly favour a green pathway while expressing comparatively less backing for the twin-track approach.

Across all metrics, hydrogen is deemed safer than natural gas, while the perceived socio-economic costs of transitioning to a hydrogen home are considered more substantial than the potential disruptive (short-term) impacts, as reflected in Fig. 4c. Furthermore, consumers have largely negative perceptions of hydrogen in terms of financial investment and running costs. Nevertheless, positive emotions prevail over negative emotions (see Fig. 4c). Overall, consumers hold moderate levels of domestic hydrogen acceptance and willingness to adopt a hydrogen home before 2030, as largely dictated by perceptions of environmental benefits, and a lesser extent socio-economic benefits (see Fig. 4b). However, it should be emphasised that the level of hydrogen knowledge and awareness remains low across the UK population (see Section 5.8), thus current perceptions could prove short-lived. Importantly, the results should be gauged within a context where information provision materials may have influenced certain trends, as discussed when analysing the simplified STEEP Framework [63].

6.2. Measurement model assessment

Four conditions should be satisfied when measuring reflective constructs: item reliability, internal consistency reliability, convergent validity, and discriminant validity [279]. Across the 61 indicators composing the model, item reliability (i.e. scale reliability) is clearly supported in most cases since loadings exceed the suggested Cronbach Alpha (CA) threshold of 0.708. Satisfying this condition infers that the construct explains at least 50% of the variance in a respective indicator [186]. In one case, CA falls marginally below the cut-off value ($NE1 = 0.697$), which is unproblematic. Although PP1 has a lower than desirable CA value (0.552), other reliability and validity conditions were

fulfilled, therefore the indicator is included to support content validity [280].

Internal consistency between each set of indicators is established since Composite Reliability (CR) exceeds 0.70 for all values without breaching the upper conservative limit of 0.95 [217], as best measured via Henseler and Dijkstra rho (ρ_A) [281]. Additionally, convergent validity is confirmed since each construct converges to explain more than 50% of the variance in its indicators (see Table 2), as demonstrated by average variance extracted (AVE) values greater than 0.50 [186]. Critically, each construct can be regarded as empirically distinct since the heterotrait-monotrait (HTMT) ratio of correlations returns values comfortably below 0.85 for each construct, as reported in Table 3 [282].⁹ Furthermore, variance inflation factor (VIF) scores fall below the threshold of 3.0 in all but two instances and do not exceed the more conservative threshold of 5.0, which suggests minimal risk of multicollinearity [283].

6.3. Structural model assessment

The proposed hypotheses were tested in SmartPLS 4.1 [185] via the bootstrapping procedure (10000 sub-samples). Except for H10 ($FP \rightarrow (-)DHA$, $p = 0.006$), all relationships proved significant at the less than 0.1% level ($p < 0.001$), as reported in Table 4. Firstly, each lower-order construct has a strong and comparable influence on shaping public trust ($\beta = 0.210$ – 0.261 ; $SD = 0.021$), thereby confirming H1a–H1e. Among the five lower-order constructs, social trust has the strongest influence on public trust. In turn, public trust positively predicts domestic hydrogen acceptance (H2a: $\beta = 0.277$, $f^2 = 0.160$), in addition to mediating the relationship between each trust dimension and domestic hydrogen acceptance (H2b–H2f). Accordingly complementary partial mediation is observed within the trust-based component of the model [284,285].

Compared to public trust, the positive effect of production perceptions on domestic hydrogen acceptance is larger (H3: $\beta = 0.304$, $f^2 = 0.204$), while the influence of safety perceptions is comparatively smaller (H4: $\beta = 0.197$, $f^2 = 0.080$). However, the negative effect of perceived disruptive impacts (H5: $\beta = -0.121$, $f^2 = 0.041$) and perceived socio-economic costs (H6: $\beta = -0.175$, $f^2 = 0.079$) on domestic hydrogen acceptance is slightly smaller compared to safety perceptions. Finally, perceived relative advantage has the third most significant effect on domestic hydrogen acceptance (H7c: $\beta = 0.226$, $f^2 = 0.124$). Regarding the lower-order constructs of perceived relative advantage, perceived hob performance (H7b: $\beta = 0.613$, $t = 69.916$) is slightly more influential than perceived boiler performance (H7a: $\beta = 0.500$, $t = 65.432$), resulting in a marginally weaker mediating effect on domestic hydrogen acceptance for the latter sub-construct (H7e: $\beta = 0.138$, $t = 12.068$; H7d: $\beta = 0.113$, $t = 11.666$).

The direct effect of domestic hydrogen acceptance on willingness to adopt a hydrogen home carries the third strongest effect size across the model (H8a: $\beta = 0.333$, $f^2 = 0.137$), thereby confirming the positive association between social acceptance and adoption intention. The indirect effect of public trust, production perceptions, safety perceptions, perceived disruptive impacts, perceived socio-economic costs, and perceived relative advantage on adoption willingness (H8b–H8g) is approximately 66% smaller as compared to the direct effect on domestic hydrogen acceptance.

Alongside domestic hydrogen acceptance, positive emotions has a substantial influence on willingness to adopt a hydrogen home before 2030 (H11a: $\beta = 0.367$, $f^2 = 0.174$), whereas the effect of hydrogen knowledge and awareness (H9: $\beta = 0.226$, $f^2 = 0.037$) and negative emotions (H11b: $\beta = -0.109$, $f^2 = 0.021$) is more moderate. Lastly, financial perceptions is the least significant construct in the model, given

⁹ The lower-order constructs are excluded when assessing discriminant validity.

Table 3

Heterotrait-monotrait results for assessment of discriminant validity.

	DHA	FP	HKA	NE	PDI	ADV	PSC	PE	PP	PT	SP	WTA
DHA												
FP	0.200											
HKA	0.157	0.235										
NE	0.345	0.119	0.132									
PDI	0.298	0.092	0.094	0.511								
ADV	0.591	0.148	0.087	0.103	0.071							
PSC	0.470	0.224	0.148	0.530	0.392	0.235						
PE	0.614	0.211	0.335	0.115	0.153	0.335	0.249					
PP	0.705	0.104	0.246	0.237	0.193	0.330	0.329	0.404				
PT	0.632	0.149	0.284	0.112	0.149	0.302	0.127	0.452	0.495			
SP	0.617	0.170	0.115	0.125	0.036	0.473	0.159	0.403	0.413	0.505		
WTA	0.646	0.227	0.324	0.240	0.219	0.270	0.287	0.674	0.418	0.378	0.368	

its relatively modest effect on adoption willingness (**H10**: $\beta = 0.226$, $t = 2.773$, $f^2 = 0.005$). To summarise the findings, Fig. 5 visualises the results from the measurement and structural models, in addition to illustrating the in-sample explanatory power of the model for predicting domestic hydrogen acceptance ($R^2 = 0.674$) and adoption willingness ($R^2 = 0.503$), which is further discussed following IMPA. Additionally, Fig. 6 shows the relationships between latent constructs with p -values and t -statistics.

6.4. Insights from importance-performance map analysis

The modelling results can be further interpreted via IMPA, which aids in revealing areas of strategic importance for realising the target outcome. Among the four positive constructs predicting domestic

hydrogen acceptance, improving consumer perceptions of hydrogen production presents the foremost strategic priority and still has significant room for improvement (Latent variable (LV) score = 63.833). However, there is more scope for improving public trust in the domestic hydrogen transition (LV = 52.056), which presents the second priority (see Fig. 7 and SN10). While perceived relative advantage is the best performing construct in this part of the model (LV = 67.678), there is more value in targeting the technological dimension of domestic hydrogen acceptance compared to the safety dimension, given the difference in effect size (0.029).

Notably, negative constructs have a smaller effect size and an inferior performance to each positive construct, as illustrated in Fig. 7. Although perceived disruptive impacts and socio-economic costs should be curbed to help mitigate potential social resistance to hydrogen homes, it is more

Table 4

Results of path analysis and hypothesis testing.

Hypothesis	β -coefficient (SD)	95% bootstrap confidence intervals	t -statistic	p -value	f^2
H1a : GOV $\rightarrow$ (+) PT	0.211 (0.003)	[0.205; 0.218]	64.973	<0.001	n/a
H1b : NRG $\rightarrow$ (+) PT	0.237 (0.003)	[0.231; 0.244]	74.076	<0.001	n/a
H1c : QUAL $\rightarrow$ (+) PT	0.233 (0.004)	[0.226; 0.240]	66.216	<0.001	n/a
H1d : R&D $\rightarrow$ (+) PT	0.210 (0.003)	[0.203; 0.216]	60.785	<0.001	n/a
H1e : ST $\rightarrow$ (+) PT	0.261 (0.003)	[0.255; 0.266]	90.658	<0.001	n/a
H2a : PT $\rightarrow$ (+) DHA	0.277 (0.020)	[0.238; 0.315]	13.969	<0.001	0.160 ^a
H2b : GOV $\rightarrow$ PT $\rightarrow$ (+) DHA	0.059 (0.004)	[0.050; 0.067]	14.116	<0.001	n/a
H2c : NRG $\rightarrow$ PT $\rightarrow$ (+) DHA	0.066 (0.005)	[0.056; 0.075]	13.958	<0.001	n/a
H2d : QUAL $\rightarrow$ PT $\rightarrow$ (+) DHA	0.065 (0.005)	[0.055; 0.074]	13.771	<0.001	n/a
H2e : R&D $\rightarrow$ PT $\rightarrow$ (+) DHA	0.058 (0.004)	[0.049; 0.066]	13.347	<0.001	n/a
H2f : ST $\rightarrow$ PT $\rightarrow$ (+) DHA	0.072 (0.005)	[0.062; 0.082]	14.002	<0.001	n/a
H3 : PP $\rightarrow$ (+) DHA	0.304 (0.009)	[0.267; 0.339]	16.379	<0.001	0.204 ^a
H4 : SP $\rightarrow$ (+) DHA	0.197 (0.019)	[0.161; 0.234]	10.540	<0.001	0.080 ^b
H5 : PDI $\rightarrow$ (–) DHA	–0.121 (0.016)	[–0.153; –0.092]	7.600	<0.001	0.041 ^b
H6 : PSC $\rightarrow$ (–) DHA	–0.175 (0.015)	[–0.205; –0.146]	11.721	<0.001	0.079 ^b
H7a : BLR $\rightarrow$ (+) ADV	0.500 (0.008)	[0.485; 0.515]	65.432	<0.001	n/a
H7b : HOB $\rightarrow$ (+) ADV	0.613 (0.009)	[0.597; 0.631]	69.916	<0.001	n/a
H7c : ADV $\rightarrow$ (+) DHA	0.226 (0.019)	[0.189; 0.263]	11.947	<0.001	0.124 ^b
H7d : BLR $\rightarrow$ ADV $\rightarrow$ (+) DHA	0.113 (0.010)	[0.094; 0.132]	11.666	<0.001	n/a
H7e : HOB $\rightarrow$ ADV $\rightarrow$ (+) DHA	0.138 (0.011)	[0.116; 0.161]	12.068	<0.001	n/a
H8a : DHA $\rightarrow$ (+) WTA	0.333 (0.021)	[0.293; 0.373]	15.991	<0.001	0.137 ^b
H8b : PT $\rightarrow$ DHA $\rightarrow$ (+) WTA	0.092 (0.009)	[0.075; 0.110]	10.577	<0.001	n/a
H8c : PP $\rightarrow$ DHA $\rightarrow$ (+) WTA	0.101 (0.009)	[0.085; 0.118]	11.587	<0.001	n/a
H8d : SP $\rightarrow$ DHA $\rightarrow$ (+) WTA	0.066 (0.008)	[0.051; 0.082]	8.573	<0.001	n/a
H8e : PDI $\rightarrow$ DHA $\rightarrow$ (–) WTA	–0.041 (0.006)	[–0.053; –0.030]	6.890	<0.001	n/a
H8f : PSC $\rightarrow$ DHA $\rightarrow$ (–) WTA	–0.058 (0.006)	[–0.071; –0.047]	9.340	<0.001	n/a
H8g : ADV $\rightarrow$ DHA $\rightarrow$ (+) WTA	0.075 (0.008)	[0.061; 0.091]	9.748	<0.001	n/a
H9 : HKA $\rightarrow$ (+) WTA	0.144 (0.017)	[0.110; 0.178]	8.302	<0.001	0.037 ^b
H10 : FP $\rightarrow$ (–) WTA	–0.049 (0.018)	[–0.083; –0.015]	2.773	0.006	0.005
H11a : PE $\rightarrow$ (+) WTA	0.367 (0.021)	[0.325; 0.409]	17.422	<0.001	0.174 ^a
H11b : NE $\rightarrow$ (–) WTA	–0.109 (0.018)	[–0.146; 0.072]	5.921	<0.001	0.021 ^b

^a Moderate effect size ($0.15 \leq f^2 < 0.35$).

^b Small effect size ($0.02 \leq f^2 < 0.15$).

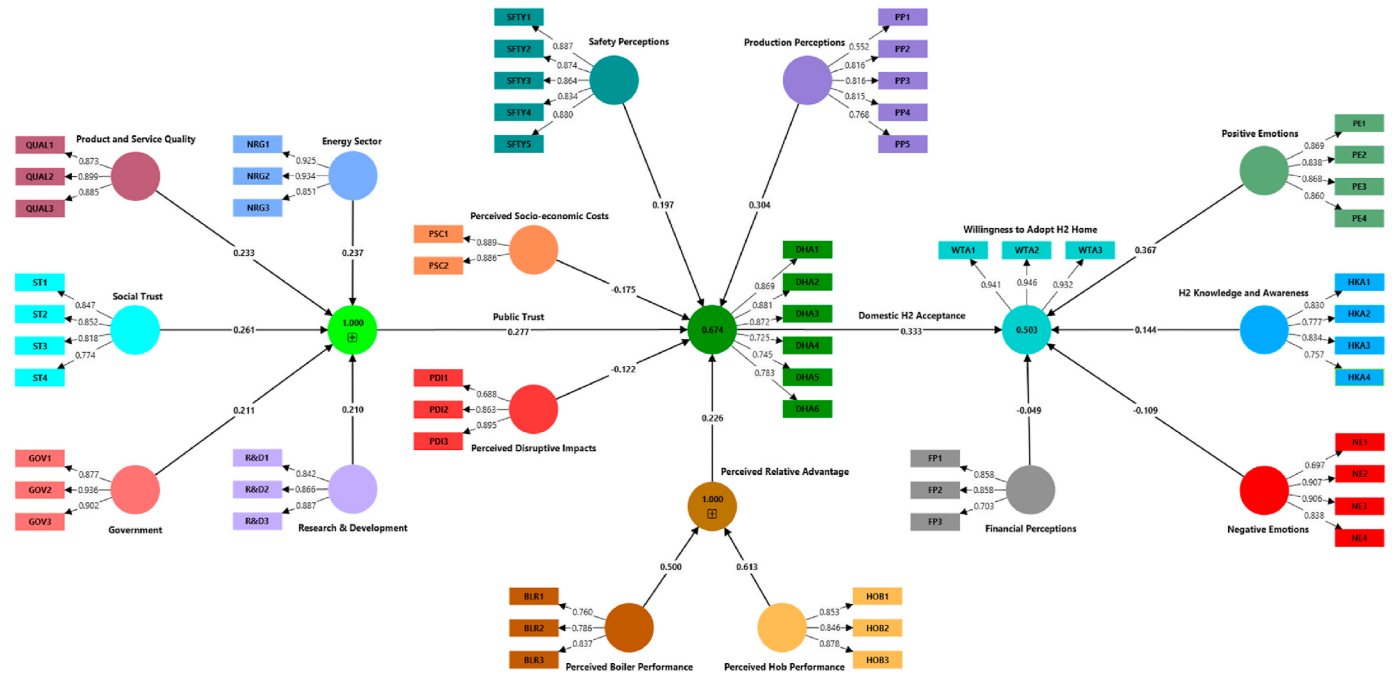


Fig. 5. Structural model path coefficients and indicator loadings.

justified to focus on the economic dimension at this juncture of the domestic hydrogen transition. Despite perceived disruptive impacts presenting the largest scope for improvement (LV = 38.878), consumers appear less concerned about associated risks such as noise and inconvenience, at least when the transition remains hypothetical and potentially several years away.

Whereas the respective positive and negative predictors of domestic hydrogen acceptance are clustered somewhat closely together within the IMPA, there is more divergence when considering the antecedents of adoption willingness. Hydrogen knowledge and awareness is the worst performing construct by a significant margin, but also has the smallest effect size (see Fig. 8 and SN10). Consequently, allocating resources towards raising hydrogen knowledge and awareness, although a likely requirement for strengthening long-term prospects for national hydrogen economies [165,286], may prove strategically unsound for increasing near-term deployment prospects for hydrogen homes [130].

Key stakeholders including policy makers should take stock that increasing domestic hydrogen acceptance is a necessary step for improving consumer willingness to adopt a hydrogen home before 2030 [64]. However, it is critical to raise the overall level of social acceptance via the perceptual pathways identified in Fig. 7, in conjunction with strengthening positive sentiment about hydrogen homes. Consolidating feelings of satisfaction, calm, confidence, and optimism towards hydrogen homes will inevitably help offset negative emotions, which is more important than addressing (negative) financial perceptions at this juncture of the prospective transition. Moreover, there is comparatively less scope to improve financial perceptions (LV = 68.390) compared to other constructs in the model.

Targeting communication campaigns across specific segments of the population such as industrial towns and socio-economically deprived communities [62], in conjunction with increasing the trialability and observability of hydrogen homes [42], presents a tangible ‘intervention point’ [287,288] for mitigating pessimism and scepticism. In parallel to directly circumventing negative emotions, decision-makers can take stock that reinforcing feelings of confidence (PE3) and optimism (PE4) towards hydrogen homes will naturally present the most direct means for bolstering technology adoption. Taken together, Figs. 7–9 present an initial snapshot of which success factors are likely to prove critical to establishing a sense of hope and curbing fears for domestic hydrogen

futures.

6.5. Predictive capabilities of the model

6.5.1. In-sample predictive power

The coefficient of determination (R^2) indicates how much variance in an outcome variable can be explained by its predictors [289,290]. While in-sample predictive power should be assessed on a case-by-case basis [291,292], a general guideline is that R^2 values of 0.25, 0.50, and 0.75 approximate weak, moderate, and substantial levels of predictive power [293]. As shown in Fig. 5, the proposed model displays a higher level of explanatory power for predicting domestic hydrogen acceptance ($R^2 = 0.674$) compared to willingness to adopt a hydrogen home ($R^2 = 0.503$). Given the nascency of modelling consumer perspectives of domestic hydrogen [130], in-sample predictive power can be considered at least moderate in both cases.

To better position the results of this study in the context of the PLS-SEM literature, Table 5 leverages findings from SN1 to provide the R^2 values for 38 target constructs retrieved from 16 studies spanning a range of country contexts. Across the sample, six constructs display substantial in-sample predictive power, whereas 13 and 17 constructs exhibit moderate and weak explanatory power, as depicted in Fig. 10. Additionally, two constructs fall below the cut-off of $R^2 \geq 0.25$, corresponding to the studies of Hasheem et al. [294] and Pan et al. [302], thereby marginally increasing the variance of the sample ($SD = 0.202$), while the average R^2 value is moderate ($M = 0.537$).

It follows that the constructs of DHA ($R^2 = 0.674$) and WTA ($R^2 = 0.503$) from the integrated model fall above 26 and 19 of the 38 target constructs reported in Table 5 and visualised in Fig. 10. This stands to reason since the in-sample predictive power of WTA lies close to the suggested guideline of 0.50, implying that the small sample is broadly representative of results across the PLS-SEM literature. Validating the results in the context of the PLS-SEM literature (see SN1) further demonstrates that both model parsimony and predictive power are achieved through an integrated approach, with the relationship between attitude and intention proving comparable to the context of solar PV acceptance and adoption in Saudi Arabia [296].

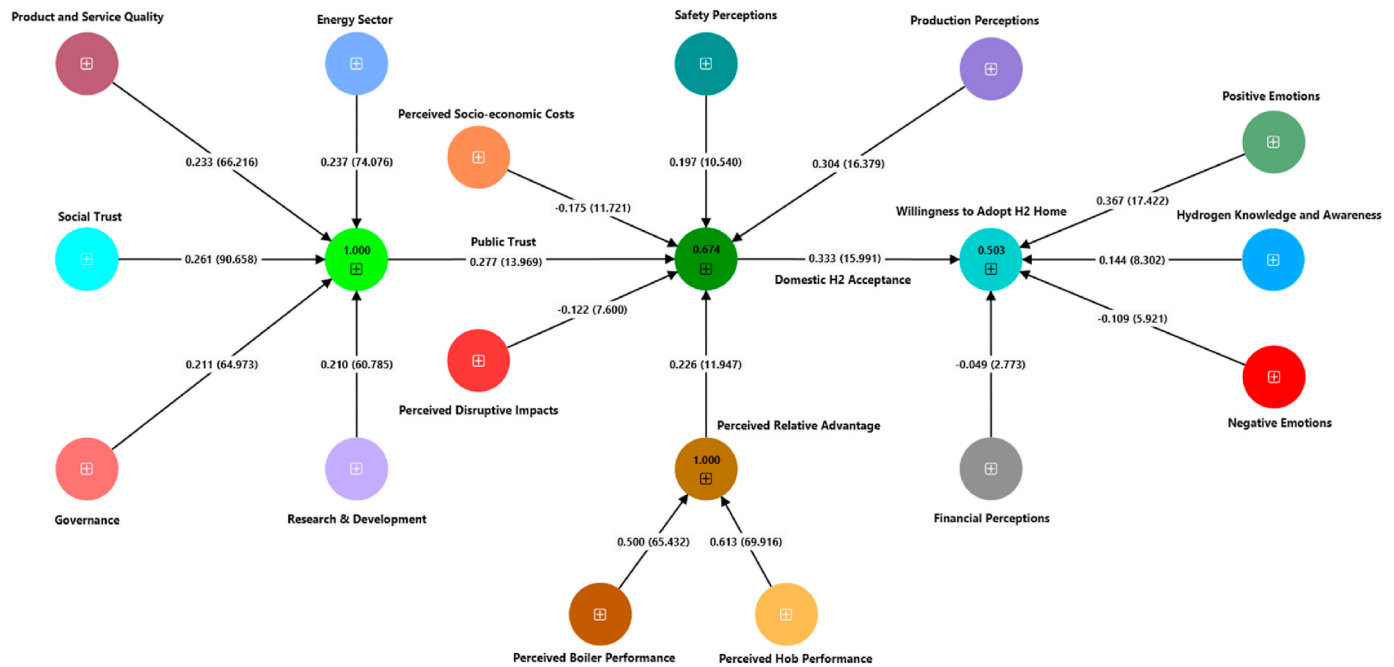


Fig. 6. Structural model path coefficients and t-statistics.

6.5.2. Out-of-sample predictive power

Assessing out-of-sample predictive power helps determine the reliability of modelling results for informing strategic decision-making and future research [173]. Shmueli et al. [309] developed the $PLS_{predict}$ tool which calculates the Stone-Geisser's Q^2 value [310,311] for each endogenous construct using a blindfolding procedure in SmartPLS. The predictive relevance of the PLS-path model for domestic hydrogen acceptance proved substantial ($Q^2 = 0.670$), while the result for adoption willingness was slightly below the desired cut-off ($Q^2 = > 0.50$) but nevertheless moderate ($Q^2 = 0.445$) [186].¹⁰

Since $PLS_{predict}$ is not strictly a statistical test (i.e. a comparative assessment), the cross-validated predictive ability test (CVPAT) provides a more robust method for evaluating out-of-sample predictive power [173]. The integrated model surpasses the indicator average (IA) prediction benchmark, given that the average loss difference between the PLS-SEM model and the IA is negative and significantly below zero, as reported in Table 6. However, the model failed to outperform the more conservative linear model (LM) prediction benchmark, which is necessary for achieving strong predictive accuracy [312]. Additionally, Table 6 shows that each endogenous construct outperformed and underperformed compared to the IA and LM benchmarks, respectively.

6.6. Comparative findings between domestic hydrogen models

6.6.1. Impacts of the integrated model on explanatory and predictive power

The integrated model of domestic hydrogen acceptance and adoption intention demonstrates the scope for increasing explanatory and predictive power by operationalising a range of perceptual, cognitive, and emotional predictors. Notably, while the DHAM explained 66.9% of the variance in domestic hydrogen acceptance via ten exogenous constructs¹¹ [61], the integrated model explains 67.4% of observed

variance via four exogenous constructs (i.e. PP, SP, PDI, and PSC) and two higher-order constructs (i.e. PT and ADV). This level of similarity demonstrates the additional explanatory power afforded by increasing construct bandwidth via higher-order constructs to capture respective sub-dimensions of public trust and perceived relative advantage.

The integrated model also demonstrates stronger explanatory power compared to the STEEP Framework, which explained 61.2% of the variance in perceived adoption potential via five exogenous constructs (i.e. SP, FP, PSC, PP, and PE) and one higher-order construct (i.e. ADV). While the outcome variables are distinct (i.e. social acceptance and perceived adoption potential), it is nevertheless noteworthy that the integrated model outperforms the STEEP Framework in this regard since the number of constructs is comparable.

Moreover, the predictive benefits of the approach taken in this study become more apparent when contrasted against the trust-based model, which also specified a path relationship between social acceptance (DHA1–DHA3) and adoption willingness [64]. Whereas this study explains 67.4% of the variance in domestic hydrogen acceptance, the trust-based model explained 56.1% of the variance in perceived community benefits (i.e. DHA4–DHA6) and a more modest 45.4% of variance in domestic hydrogen acceptance,¹² in addition to 39.4% of the variance in adoption willingness [64]. As a result, the predictive superiority of the integrated model is attested to, since 50.3% of the variance in adoption willingness could be explained by domestic hydrogen acceptance, hydrogen knowledge and awareness, financial perceptions, positive emotions, and negative emotions, as captured in Fig. 5.

Mirroring the observations for explanatory predictive power, Table 7 demonstrates the benefits of adopting an integrated approach in terms of out-of-sample predictive power. Additionally, PLS-SEM supports a robust method for statistically comparing predictive performance using a range of metrics and techniques including the root mean squared error (RMSE) and mean absolute error (MAE) vis-à-vis $PLS_{predict}$ [170], the CVPAT [173,312], and the Bayesian information criterion (BIC) [313]. The BIC helps identify the model that best optimises predictive accuracy, while balancing model fit and complexity to avert overfitting [313] (i.e.

¹⁰ At the indicator level, Q^2 measured 0.366 and 0.507 for domestic hydrogen acceptance ($M = 0.446$), and 0.391 and 0.395 for willingness to adopt a hydrogen home before 2030 ($M = 0.393$).

¹¹ Hydrogen energy awareness (i.e. HKA2, HKA4), subjective knowledge of hydrogen fuel (i.e. HKA1), Public Trust (i.e. NRG3, ST1–ST4), PP, SP, PDI, PSC, Perceived Community Benefits (i.e. DHA4–DHA6), PE, and NE.

¹² As directly predicted by perceived community benefits and its mediating path relationships (i.e. to PT, TP, SP, and PP).

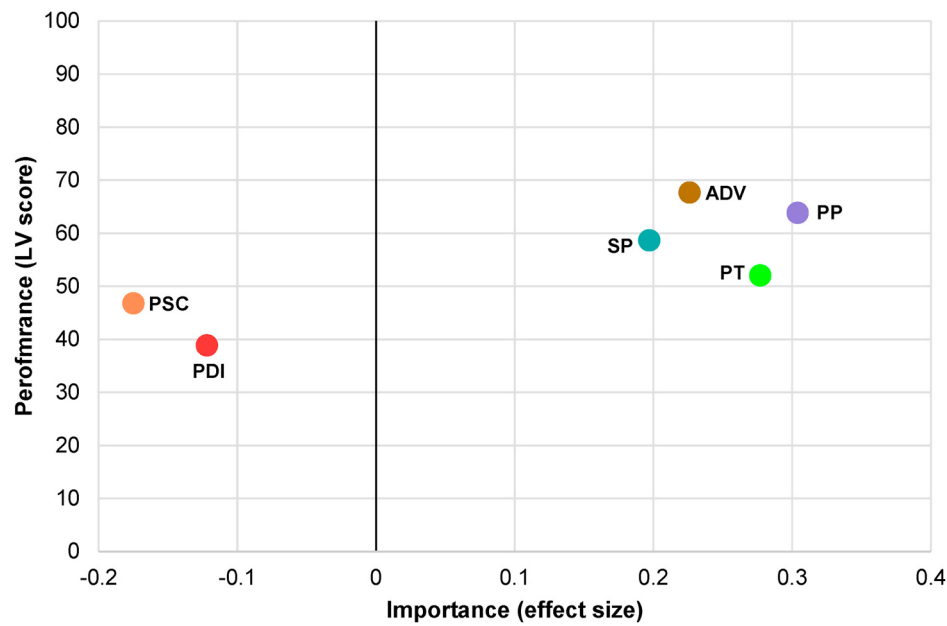


Fig. 7. Importance-performance map analysis for domestic hydrogen acceptance.

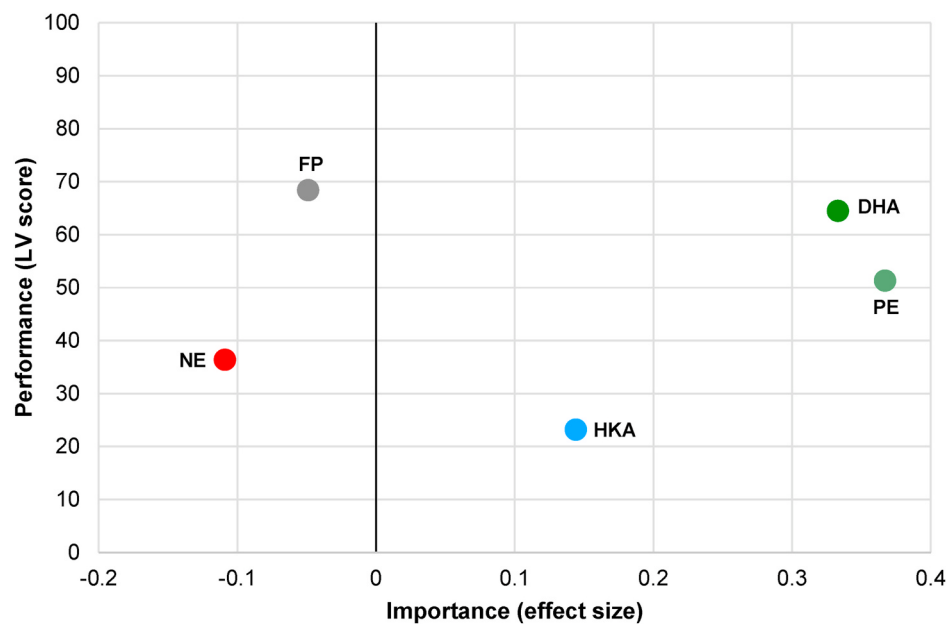


Fig. 8. Importance-performance map analysis for willingness to adopt a hydrogen home before 2030.

a model with a BIC of -250 is preferred over a BIC of -25) [313].

Given that willingness to adopt a hydrogen home is operationalised identically within the corresponding trust-based model [64] and the integrated framework depicted in Fig. 3, comparative analysis across different metrics is feasible. Table 8 confirms the superior predictive capabilities of the integrated approach across each statistical benchmark. This improvement supports the premise that cognitive and emotional factors, alongside rational thought, will take on increasing importance as consumers move through the innovation-decision for hydrogen homes, wherein a range of perceptual antecedents shape initial acceptance dynamics.

6.6.2. Impacts of the integrated model on path coefficients

To extend the comparative assessment, Table 9 considers specific changes in path coefficients between the integrated model and prior

approaches, thereby providing a systematic breakdown at the construct level. To help interpret the results and enable comparison across predictors, the observed difference between beta coefficients (β) is also calculated in percentage terms, leading to the following cut-offs: $<25\%$ $\Delta\beta$ = non-significant; $25\% \leq \Delta\beta < 50\%$ = small change in statistical significance; $50\% \leq \Delta\beta < 100\%$ = moderate change in statistical significance; $100\% \leq \Delta\beta < 250\%$ = large change in statistical significance; $\geq 250\%$ $\Delta\beta$ = very large change in statistical significance. The following patterns are observed in the modelling results: 4 results are non-significant; 7 results show a small change in statistical significance; 2 results present a moderate change; 1 result demonstrates a large change; and 2 results correspond to a very large change.

The most significant changes ($>1110\%$) are observed in relation to hydrogen knowledge awareness, which is non-significant in predicting domestic hydrogen acceptance [61], whether modelled as a combined

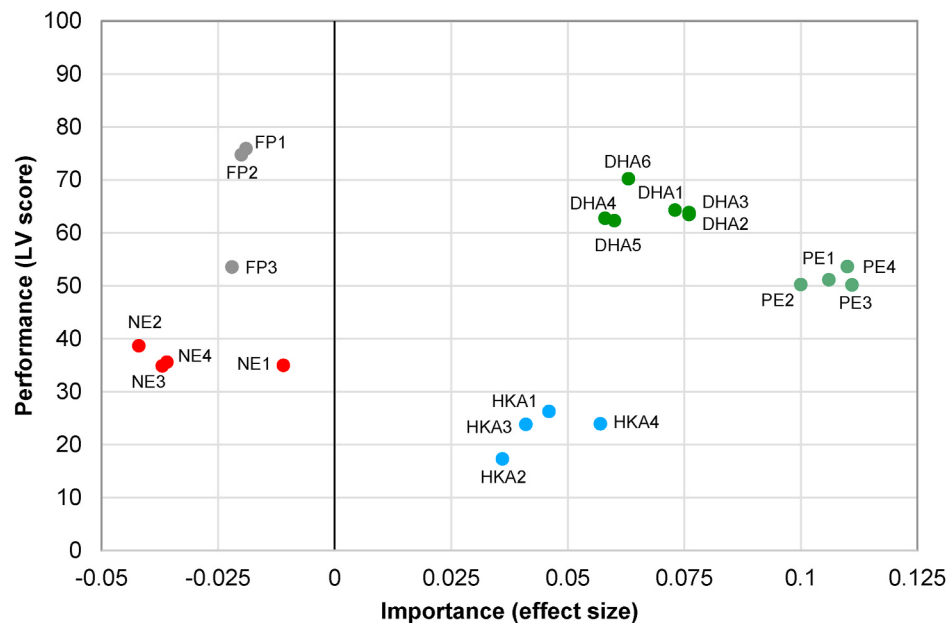


Fig. 9. Importance-performance map analysis for adoption willingness at the indicator level.

construct or separated into its constituent parts (see Table 9). Although subjective knowledge of hydrogen fuel (HKA1) remains non-significant in predicting social acceptance (i.e. DHA1–DHA3) or adoption willingness (i.e. WTA1–WTA3), both hydrogen awareness (i.e. HKA2–HKA4) and the combined construct conceived in this study (i.e. HKA1–HKA4) become statistically significant predictors of adoption willingness ($p < 0.001$).

In practical terms, this discrepancy means that as consumers navigate the innovation-decision process [44] and begin to consider the suitability of adopting a hydrogen home, knowledge and awareness of the technology takes on increasing importance. Statistical analysis of qualitative responses to this dataset supports this rationale, since knowledge and awareness of renewable energy technologies also proved more significant in predicting adoption willingness compared to social acceptance [165].

The more granular findings presented in Fig. 9 further demarcate the interactions between knowledge, awareness, and adoption willingness, revealing that awareness is more influential than subjective knowledge. Notably, the literature supports the notion that technical or objective knowledge may fail to translate into higher technology adoption intention [314,315], which infers limitations regarding the potential influence of subjective knowledge. By contrast, perceived familiarity (i.e. a combined sense of subjective knowledge and awareness) and subsequent experience can support enabling conditions for market uptake [315–317], reflecting the imperative to bolster the observability and trialability of hydrogen homes [62].

The integrated model also reveals more intricate dynamics regarding the role of safety perceptions in shaping consumer attitudes towards hydrogen homes. A substantial change is detected between operationalising safety perceptions as a direct predictor in the DHAM ($\beta = 0.057$, $t = 2.833$) [61] compared to integrating perceived community benefits into the acceptance construct as presented in Fig. 6 ($\beta = 0.197$, $t = 10.540$). This result is consistent with the associated trust-based model, wherein safety perceptions positively and significantly predicted perceived community benefits ($\beta = 0.232$, $t = 10.537$) [64], which is further reflected via alignment to the STEEP Framework (see Table 9).

The main implication is that perceptions of hydrogen safety – as represented by both infrastructural and technological developments (see Section 5.3) – will have a strong bearing on the degree to which the public anticipates potential environmental health benefits from the

hydrogen switchover. A similar dynamic is observed for perceived socio-economic costs, which becomes significantly more influential in the integrated model compared to the DHAM ($\beta = +0.177$, $t = +8.289$). It follows that perceptions of energy security and fuel poverty risks will feed more directly into shaping community-level acceptance, as partly dictated by mechanisms of distributional (in-)justice [157,318]. Thus, the highlighted critical success and resistance factors (i.e. SP and PSC) become more prominent predictors when perceived community benefits is factored into the social acceptance equation.

A moderate amplifying effect is also observed at the emotional level. The change is specific to positive emotions which is approximately 69% more influential in the integrated model compared to the DHAM, as reported in Table 9, whereas the influence of negative emotions remains relatively consistent between models. Thus, feelings of calm, confidence, satisfaction, and optimism will tangibly transmit towards perceptions of economic, social, and environmental benefits associated with the domestic hydrogen transition. By empirically validating this logical relationship, the integrated model attests to the importance of human emotions in shaping behavioural intentions towards emerging, low-carbon energy technologies [155,159,319], while underscoring the multi-dimensional nature of domestic hydrogen acceptance [120].

7. Conclusion

7.1. Practical and theoretical contributions

Through an integrated conceptual framework, this study advances insights on the critical drivers and barriers shaping social acceptance and early adoption prospects for domestic hydrogen in the UK. Departing from previous modelling approaches [61–63], a dual focus on acceptance and adoption dynamics is presented to capture the initial stages of the innovation-decision process for hydrogen homes. In doing so, the underlying premise of the unified theory of domestic hydrogen acceptance [42] is explicitly captured for the first time by juxtaposing perceptual, cognitive, and emotional factors, while expanding previous insights from a more concise, trust-based model [64].

Addressing the first research objective, the critical drivers of domestic hydrogen acceptance include perceptions of hydrogen production pathways, public trust, perceived relative advantage, and safety perceptions. Fig. 7 affirms that the environmental tenets of the domestic

Table 5

In-sample predictive power of different target constructs in PLS-SEM studies.

Study	Research focus and context	Target construct(s)	R ²
[295]	Factors affecting university students' new technology entrepreneurial performance in China	<ul style="list-style-type: none"> • Entrepreneurial intention • Entrepreneurial performance 	0.568 0.568
[296]	Consumer acceptance of solar PV in Saudi Arabia	<ul style="list-style-type: none"> • Consumer attitude • User behaviour (intention) 	0.760 0.563
[294]	Consumer acceptance of solar PV in Pakistan	<ul style="list-style-type: none"> • Consumer attitude • Purchase intention 	0.400 0.211
[297]	Consumer acceptance of a home energy management system in South Korea	<ul style="list-style-type: none"> • Perceived ease of use • Perceived usefulness • Intention to use 	0.486 0.814 0.703
[21]	Consumer acceptance of smart meter technology in Malaysia	<ul style="list-style-type: none"> • Behavioural intention 	0.962 ^a
[298]	Entrepreneurial tendencies among engineering students in Pakistan	<ul style="list-style-type: none"> • Entrepreneurial behaviour 	0.488
[299]	Determinants of active online learning in the Chinese smart learning environment	<ul style="list-style-type: none"> • Active online learning 	0.445
[300]	Drivers of data-drive innovation by organisations in Australia	<ul style="list-style-type: none"> • Data-driven innovation development 	0.655
[301]	Determinants of cultural orientation among Malaysian entrepreneurs	<ul style="list-style-type: none"> • Cultural orientation 	0.505
[302]	Acceptance and use of electric bicycle-sharing systems in China	<ul style="list-style-type: none"> • Perceived environmental value • Perceived pleasure • Perceived usefulness • Behaviour attitude • Behaviour intention • Actual behaviour 	0.393 0.279 0.143 0.475 0.328 0.277
[303]	Determinants of E-banking customer satisfaction and loyalty in Pakistan	<ul style="list-style-type: none"> • Trust in Islamic e-banking • Religiosity • E-customer loyalty 	0.488 0.692 0.870
[304]	Examines the impact of interactivity (i.e. computer-mediated environments) on communication quality and process satisfaction among university students in Southern California	<ul style="list-style-type: none"> • Communication quality • Process satisfaction 	0.485 0.688
[305]	Predictors of network embeddedness and innovation performance of small- and medium-sized enterprises in Pakistan	<ul style="list-style-type: none"> • Absorptive capacity • Innovation performance 	0.744 0.396
[306]	Examines the antecedents and relationship between corporate reputation and customer response	<ul style="list-style-type: none"> • Corporate reputation • Customer satisfaction • Customer loyalty 	0.734 0.306 0.565
[307]	Examines the factors influencing the reputation of non-profit organisations	<ul style="list-style-type: none"> • Competence • Likeability 	0.659 0.752
[308]	Examines the relationship between corporate social responsibility, green construction, and sustainable development in China	<ul style="list-style-type: none"> • Green design • Green procurement • Carbon emissions • Sustainable construction • Sustainable waste management • Ecosystem sustainability 	0.349 0.475 0.845 0.343 0.261 0.728

^a 0.962 can be considered an artificially (or excessively) high R² value but is nonetheless included in the sample. Removing this data point has a negligible effect on the sample average (R² = 0.525) or variance (SD = 0.192).

hydrogen transition, as implicit within the twin-track production approach [129], are paramount to enabling social acceptance for hydrogen homes. While this observation is strongly in line with prior models [61,64], the results depart somewhat from previous iterations since public trust and safety perceptions share nearer levels of equivalence in predicting social acceptance.

Notably, this study makes a novel contribution by operationalising perceived relative advantage as an antecedent of acceptance as opposed to adoption potential [62,63], which corresponds to the third most important critical success factor behind production perceptions and public trust. In terms of critical barriers or resistance factors, perceived socio-economic costs is more influential than perceived disruptive impacts, which marks a notable reversal from the DHAM (see Table 9) [61], reflecting the strong interaction between macro-economic risk factors and community-level acceptance.

Regarding the second research objective, the critical success factors of adoption willingness are domestic hydrogen acceptance, hydrogen knowledge and awareness, and positive emotions, while barriers include

financial perceptions and negative emotions. Insights from IMPA (see Section 6.4) suggest emotional factors are currently more influential than cognitive processes and associated rational thought when the adoption decision remains hypothetical and distant. This observation aligns to prior results [263,264,320], signalling the more subdued role of consumer knowledge, financial factors, and rational thinking when technologies are yet to reach commercialisation.

While affective drivers of adoption intention feature prominently, alongside underlying perceptions and attitudes shaping social acceptance, there is more scope for increasing positive emotions to enhance deployment prospects for hydrogen homes. At present, negative emotions present more of a barrier to adoption willingness than financial perceptions, further suggesting that emotional response may outweigh rational thought during the formative phase of the transition [42], which sees trust mechanisms strongly shape the formation of consumer attitudes [50,321].

The final research question has been answered emphatically by comparing results from available models. As reported in Section 6.6, the

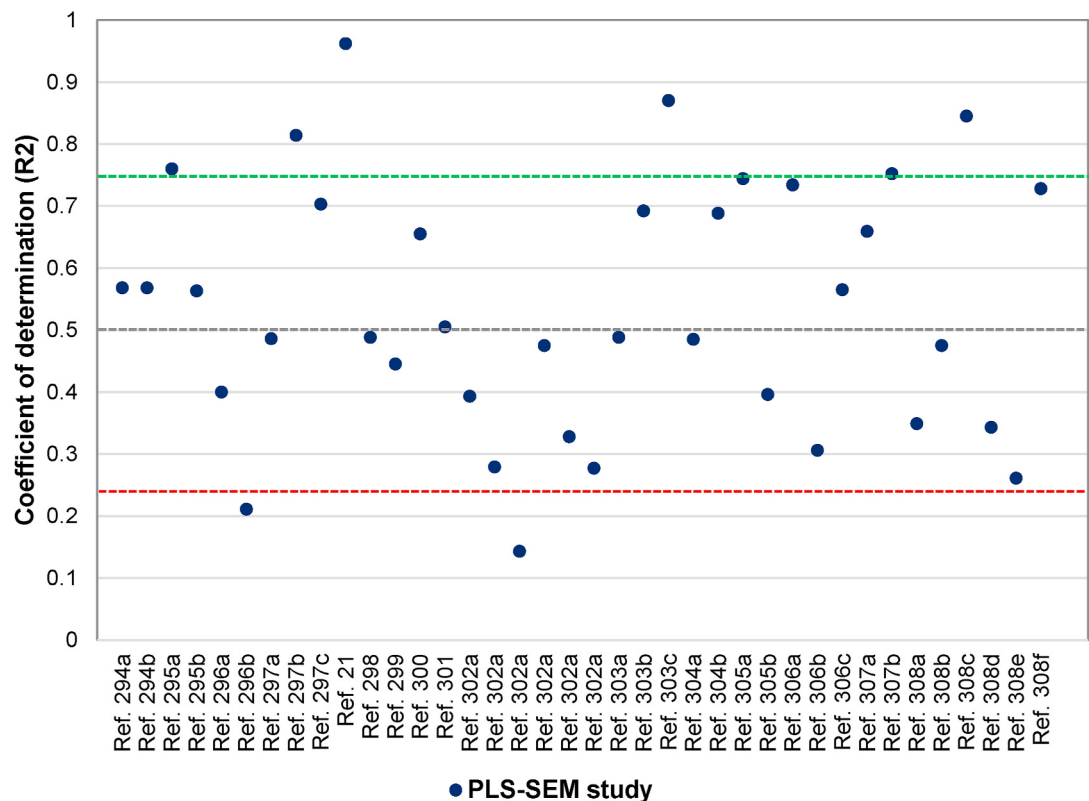


Fig. 10. Scatter plot of in-sample predictive power for target constructs ($N = 38$) in the PLS-SEM sample ($N = 16$) discussed in Supplementary Note 1. The dashed red line demarcates the cut-off for a weak R^2 value ($0.25 > R^2 \leq 0.50$). The grey dashed line demarcates the cut-off for a moderate R^2 value ($0.50 > R^2 \leq 0.75$). The green dashed line demarcates the cut-off for a strong R^2 value (≥ 0.75). (For interpretation of the references to colour in this figure legend, the reader is referred to the Web version of this article.)

Table 6
CVPAT benchmark and results for predictive ability test.

Target construct	PLS-SEM vs Indicator average (IA)				
	PLS loss	IA loss	Average loss difference	t-value	p-value
Domestic H2 Acceptance	2.534	4.595	−2.061	20.527	<0.001
Perceived Relative Advantage	2.631	5.840	−3.209	24.881	<0.001
Public Trust	2.347	5.534	−3.187	30.865	<0.001
Adoption willingness	0.631	1.039	−0.408	16.063	<0.001
Overall	2.272	4.976	−2.704	35.622	<0.001
	PLS-SEM vs Linear model (LM)				
	PLS loss	LM loss	Average loss difference	t-value	p-value
Domestic H2 Acceptance	2.534	2.242	+0.292	9.535	<0.001
Perceived Relative Advantage	2.631	0.000	+2.631	42.915	<0.001
Public Trust	2.347	0.000	+2.347	52.701	<0.001
Adoption willingness	0.631	0.633	−0.002	0.317	0.751
Overall	2.272	0.495	+1.777	60.319	<0.001

Table 7
Comparison of out-of-sample predictive power between modelling approaches.

Model specification	Q ² value for domestic hydrogen acceptance	Q ² value for willingness to adopt a hydrogen home	PLS-SEM vs Indicator average for overall model (t-value)
Integrated model	0.670	0.445	35.622
DHAM [61]	0.653	n/a	20.971
STEEP Framework [63]	n/a	0.608	25.985
Trust-based model [64]	0.434	0.178	31.798

Table 8

Model comparison between trust-based and integrated frameworks.

Indicators/construct	Root mean square error ^a		Mean absolute error ^b	
	Trust-based model	Integrated model	Trust-based model	Integrated model
WTA1	0.924	0.783	0.735	0.621
WTA2	0.932	0.790	0.748	0.624
WTA3	0.952	0.810	0.770	0.642
Cross validated predictive ability test				
	Trust-based model	Integrated model	Average loss difference	t-value (p-value)
Willingness to adopt a hydrogen home	0.875	0.631	−0.244	13.842 (<0.001)
Overall model	2.114	2.076	−0.038	13.577 (<0.001)
Bayesian information criterion				
	Trust-based model	Integrated model		
Willingness to adopt a hydrogen home		−910.436	−1245.290	

Bold text highlights stronger predictive capabilities.

^a The square root of the average of the squared differences between the predictions and the actual observations.^b The average absolute difference between the predicted and the actual values.

integrated model demonstrates higher predictive capabilities than its predecessors. Thus, this analysis aligns to the seminal findings espoused via the UTUAT [14] and subsequent iterations [25,208], with a wealth of studies underscoring the explanatory and predictive advantages of leveraging integrated frameworks [20,322–324] or unified modelling approaches [26,325,326]. This study palpably demonstrates the ability to advance theoretical understanding and empirical insights through the development and testing of models [60], as supported by the exploratory, causal-predictive nature of PLS-SEM [168,289,327].

Importantly, this analysis deviates from the unified theory of

domestic hydrogen acceptance [42] by linking cognitive processes with adoption intention, thereby exploring an alternative causal link to what was tested and proved non-significant within the DHAM [61]. More explicitly, the integrated model posits relationships between a group of (positive and negative) perceptual antecedents and social acceptance, which serves as a proxy for consumer attitude. In line with established psychological theories [3,46,47], an individual's attitude towards acceptance, whether endorsing or simply tolerating a given technology [120,328] is a strong predictor of behavioural intention [264,329], which manifests through cognitive processes, financial perceptions, and

Table 9

Comparison of structural path coefficients between modelling approaches.

Construct	Model specification		
	DHAM ^a	Integrated model (DHA) ^b	Change in β (%)
Public Trust	0.198 (10.207)	0.277 (13.969)	0.079 ^e (+39.9)
Production Perceptions	0.214 (10.897)	0.304 (16.379)	0.090 ^e (+42.1)
Safety Perceptions	0.057 (2.833)	0.197 (10.540)	0.140 ^g (+245.6)
Perceived Disruptive Impacts	−0.092 (5.450)	−0.122 (7.600)	0.030 ^e (+32.6)
Perceived Socio-economic Costs	−0.058 (3.432)	−0.175 (11.721)	0.117 ^g (+201.7)
STEEP Framework^c			
Safety Perceptions	0.193 (9.679)	0.197 (10.540)	0.004 (+2.1)
Perceived Relative Advantage	0.179 (8.674)	0.226 (11.947)	0.047 ^e (+26.3)
Perceived Socio-Economic Costs	−0.126 (8.409)	−0.175 (11.721)	0.049 ^e (+38.9)
Production Perceptions	0.241 (13.441)	0.304 (16.379)	0.063 ^e (+26.1)
DHAM^a			
Subjective Hydrogen Knowledge (HKA1)	−0.008 (0.731)	−0.014 (0.639)	0.006 (+25.0)
Hydrogen Awareness (HKA2–HKA4)	0.010 (0.678)	0.160 (7.020)	0.150 ^h (+1500.0)
Hydrogen Knowledge and Awareness (HKA1–HKA4)	0.012 (0.423)	0.144 (8.302)	0.132 ^h (+1110.0)
DHAM^a			
Positive Emotions	0.217 (12.599)	0.367 (17.422)	0.150 ^f (+69.1)
Negative Emotions	−0.138 (8.325)	−0.109 (5.921)	0.029 (−21.0)
STEEP Framework^c			
Positive Emotions	0.376 (19.909)	0.367 (17.422)	0.009 (2.5)
Financial Perceptions	−0.082 (5.311)	−0.049 (2.773)	0.033 ^e (40.2)

^a Domestic Hydrogen Acceptance (i.e. DHA1, DHA2, DHA3).^b Domestic Hydrogen Acceptance (extended) (i.e. DHA1, DHA2, DHA3, DHA4, DHA5, DHA6).^c Perceived Adoption Potential (i.e. WTA1, WTA2, WTA3 combined with DHA4, DHA5, DHA6).^d Willingness to Adopt a Hydrogen Home (WTA1, WTA2, WTA3).^e Small change in statistical significance.^f Moderate change in statistical significance.^g Large change in statistical significance.^h Very large change in statistical significance.

emotional response.

The strong path relationship between domestic hydrogen acceptance and adoption willingness ($\beta = 0.333, p < 0.001$) further corroborates the assertion of Dwivedi et al. [330] that attitudinal parameters should form an integral part of unified approaches towards modelling the link between acceptance, adoption intention, and subsequent decision-making for consumer technologies. In conjunction, it should be recognised that affective response is likely to play a pivotal role in shaping both acceptance and adoption dynamics (see Table 9). Critically, this observation motivates the need for deeper understanding of human emotions in shaping the innovation-decision process for residential energy technologies (see Section 7.2).

7.2. Implications for future research

Certain limitations associated with the research design and sampling characteristics, alongside recognition that actual consumer behaviour could not be captured at this juncture, have been discussed in earlier outputs [62,63]. While a research stream on hydrogen-related developments in the UK provides a useful starting point and is contextually relevant to emerging net-zero policy [112], behavioural-related insights from a single dataset at a specific point in time are naturally limited. Nevertheless, this study provides a stepping-stone for developing a more comprehensive understanding regarding the interplay between perceptual, cognitive, and emotional antecedents in shaping consumer attitudes towards hydrogen homes. The natural evolution of this contribution lies with expanding the longitudinal evidence base on hydrogen acceptance [66,134], in addition to advancing cross-national studies [261,331]. Such additions would enhance understanding of both the temporal [264,332] and cultural dynamics shaping public perceptions [333,334].

As advancements in research methods and computational power continue to shape the trajectory of scholarship on consumer behaviour and technology acceptance [335–337], opportunities beckon to close the gap on understanding the interplay between cognitive processes, rational decision-making, and emotional response. In a notable contribution to the technology acceptance literature, Dimoka and Davis [338] investigated “the neural mechanisms underlying technology adoption” by positing the intriguing question: “Where does TAM reside in the brain?” This innovative trajectory manifested under the umbrella of neuroscience for information systems (NeuroIS) research [339], which was subsequently contextualised in relation to decision-making, and cognitive, emotional, and social processes [340].

Fundamentally, NeuroIS studies leverage state-of-the-art tools such as functional Magnetic Resonance Imaging (fMRI), and psychophysiological technologies such as electrocardiogram (ECG) and eye tracking to capture objective data directly from the human brain and body [335].¹³ Dimoka and Davis [338] contend that “by directly asking the brain, not the person, functional neuroimaging tools allow an objective, reliable and unbiased measurement of thoughts, beliefs, and feeling and link them to human choices, decisions, and behaviour.” The efficacy of adopting a NeuroIS-based approach has been demonstrated across several novel domains within recent years by scholars such as Benbasat et al. [341],¹⁴ Casado-Aranda et al. [342–344],¹⁵ and Venkatraman et al. [345]. Critically, researchers have also recognised the potential to develop a deeper understanding of human response to climate change and sustainable technologies through neuroscience

[346,347]. Acknowledging this trajectory and reflecting the resonance between NeuroIS and the integrated framework depicted in Fig. 3, researchers may leverage tools from the neurosciences – with the requisite guidance and training from specialists – to advance cross-disciplinary evidence on the innovation-decision process for hydrogen homes.

Ahead of the UK government taking a strategic decision on whether homes should play a part in the country’s energy future, researchers can seek to better understand the neural, psychological, and emotional signatures underlying domestic hydrogen acceptance and adoption. As a complementary method to qualitative techniques and quantitative modelling [348], implementing a neuroscience for hydrogen systems (‘NeuroH2’) approach can help address a question that has yet to be asked social scientists, namely, where does (hydrogen) energy technology acceptance reside in the brain and body? Net-zero stakeholders should increasingly support the formation of transdisciplinary research teams to tackle this question, in view of wider implications for advancing a national hydrogen economy and accelerating the energy transition.

CRediT authorship contribution statement

Joel A. Gordon: Writing – review & editing, Writing – original draft, Visualization, Validation, Methodology, Investigation, Formal analysis, Data curation, Conceptualization. **Nazmiye Balta-Ozkan:** Supervision, Project administration, Funding acquisition, Conceptualization. **Anwar Ul Haq:** Supervision, Methodology, Investigation, Conceptualization. **Sayed Ali Nabavi:** Supervision, Project administration, Funding acquisition.

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. Joel A. Gordon reports financial support was provided by Engineering and Physical Sciences Research Council in partnership with Cadent Gas Ltd. If there are other authors, they declare that they have no known competing financial interests or personal relationships that could have appeared to influence the work reported in this paper.

Acknowledgements

This research was supported by the UK Research and Innovation Engineering and Physical Sciences Research Council (UKRI-EP/SRC) Grant EP/T518104/1, and sponsored by Cadent Gas Ltd.

Appendix A. Supplementary data

Supplementary data to this article can be found online at <https://doi.org/10.1016/j.ijhydene.2024.11.061>.

References

- [1] Icek Ajzen, Fishbein M. *Understanding attitudes and predicting social behavior*. Englewood Cliffs, NJ, USA: Prentice-Hall; 1980.
- [2] Fishbein M, Ajzen I. *Belief, attitude, intention, and behavior: an introduction to theory and research*, vol. 10. Reading, MA: Addison-Wesley; 1975.
- [3] Ajzen I. The theory of planned behavior. *Organ Behav Hum Decis Process* 1991; 50:179–211. [https://doi.org/10.1016/0749-5978\(91\)90020-T](https://doi.org/10.1016/0749-5978(91)90020-T).
- [4] Labay DG, Kinnear TC. Exploring the consumer decision process in the adoption of solar energy systems. *Source. J Consum Res* 1981;8:271–8.
- [5] Hitt MA, Tyler BB. Strategic decision models: integrating different perspectives. *Strat Manag J* 1991;12:327–51.
- [6] Matute J, Palau-Saumell R, Meyer J, Derqui B, Jiménez-Asenjo N. Are you getting it? Integrating theories to explain intentions to get vaccinated against COVID-19 in Spain. *J Risk Res* 2022;25:1055–74.
- [7] Ayeh JK. Travellers’ acceptance of consumer-generated media: an integrated model of technology acceptance and source credibility theories. *Comput Hum Behav* 2015;48:173–80.

¹³ See Table 1 in Dimoka et al. [335] for a list of commonly used neuro-psychological tools.

¹⁴ Demonstrating how ethnicity and gender shape consumer preferences in technology-mediated environments.

¹⁵ Showing how trust signals differ between users in an online purchasing environment, and how neural aversive biases may exist towards product labelling.

- [8] Joo J, Sang Y. Exploring Koreans' smartphone usage: an integrated model of the technology acceptance model and uses and gratifications theory. *Comput Hum Behav* 2013;29:2512–8.
- [9] Tate M, Evermann J, Gable G. An integrated framework for theories of individual attitudes toward technology. *Inf Manag* 2015;52:710–27.
- [10] Taylor S, Todd P. Assessing IT usage: the role of prior experience. *MIS Q* 1995;19:561–70.
- [11] Pynoo B, Tondeur J, Van Braak J, Duyck W, Sijnave B, Duyck P. Teachers' acceptance and use of an educational portal. *Comput Educ* 2012;58:1308–17.
- [12] Ho LH, Hung CL, Chen HC. Using theoretical models to examine the acceptance behavior of mobile phone messaging to enhance parent–teacher interactions. *Comput Educ* 2013;61:105–14.
- [13] Yang H-H, Su C-H. Learner behaviour in a MOOC practice-oriented course: in empirical study integrating TAM and TPB. *Int Rev Res Open Dist Learn* 2017;18:35–63.
- [14] Venkatesh V, Morris MG, Davis GB, Davis FD. User acceptance of information technology: toward a unified theory. *MIS Q* 2003;27:425–78.
- [15] Attuquayefio S, Addo H. Review of studies with UTAUT as conceptual framework. *Eur Sci J* 2014;10:249–58.
- [16] Palau-Saumell R, Forgas-Coll S, Sánchez-García J, Robres E. User acceptance of mobile apps for restaurants: an expanded and extended UTAUT-2. *Sustainability* 2019;11:1210.
- [17] Al-Saedi K, Al-Emran M, Ramayah T, Abusham E. Developing a general extended UTAUT model for M-payment adoption. *Technol Soc* 2020;62:101293.
- [18] Patil P, Tamilmani K, Rana NP, Raghavan V. Understanding consumer adoption of mobile payment in India: extending Meta-UTAUT model with personal innovativeness, anxiety, trust, and grievance redressal. *Int J Inf Manag* 2020;54:102144.
- [19] Nordhoff S, Louw T, Innamaa S, Lehtonen E, Beuster A, Torrao G, et al. Using the UTAUT2 model to explain public acceptance of conditionally automated (L3) cars: a questionnaire study among 9,118 car drivers from eight European countries. *Transport Res F Traffic Psychol Behav* 2020;74:280–97.
- [20] Nordhoff S, Malmsten V, van Arem B, Liu P, Happee R. A structural equation modeling approach for the acceptance of driverless automated shuttles based on constructs from the Unified Theory of Acceptance and Use of Technology and the Diffusion of Innovation Theory. *Transport Res F Traffic Psychol Behav* 2021;78:58–73.
- [21] Alkaws G, Ali N, Baashar Y. The moderating role of personal innovativeness and users experience in accepting the smart meter technology. *Appl Sci* 2021;11:3297.
- [22] Ahn M, Kang J, Hustvedt G. A model of sustainable household technology acceptance. *Int J Consum Stud* 2016;40:83–91.
- [23] Lau LS, Choong YO, Wei CY, Seow AN, Choong CK, Senadji A, et al. Investigating nonusers' behavioural intention towards solar photovoltaic technology in Malaysia: the role of knowledge transmission and price value. *Energy Pol* 2020;144:111650.
- [24] Aggarwal AK, Syed AA, Garg S. Factors driving Indian consumer's purchase intention of roof top solar. *Int J Energy Sect Manag* 2019;13:539–55.
- [25] Venkatesh V, Thong JY, Xu X. Consumer acceptance and use of information technology: extending the unified theory of acceptance and use of technology. *MIS Q* 2012;36:157–78.
- [26] Kulviwat S, Bruner GC, Kumar A, Nasco SA, Clark T. Toward a unified theory of consumer acceptance technology. *Psychol Market* 2007;24:1059–84.
- [27] Faiers A, Cook M, Neame C. Towards a contemporary approach for understanding consumer behaviour in the context of domestic energy use. *Energy Pol* 2007;35:4381–90.
- [28] Pavlou PA. Consumer acceptance of electronic commerce: integrating trust and risk with the technology acceptance model. *Int J Electron Commer* 2003;7:101–34.
- [29] Chen C Der, Fan YW, Farn CK. Predicting electronic toll collection service adoption: an integration of the technology acceptance model and the theory of planned behavior. *Transport Res C Emerg Technol* 2007;15:300–11.
- [30] Gregor S. The nature of theory in information systems. *Source. MIS Q* 2006;30:611–42.
- [31] Momani AM, Jamous M, Jamous MM. The evolution of technology acceptance theories. *Intern J Contemp Comput Res* 2017;1:51.
- [32] Huijts NMA, Molin EJE, Steg L. Psychological factors influencing sustainable energy technology acceptance: a review-based comprehensive framework. *Renew Sustain Energy Rev* 2012;16:525–31.
- [33] Schulte E, Scheller F, Sloot D, Bruckner T. A meta-analysis of residential PV adoption: the important role of perceived benefits, intentions and antecedents in solar energy acceptance. *Energy Res Social Sci* 2022;84:102339.
- [34] Neves C, Oliveira T, Santini F. Sustainable technologies adoption research: a weight and meta-analysis. *Renew Sustain Energy Rev* 2022;165:112627.
- [35] Devine-Wright P. Beyond NIMBYism: towards an integrated framework for understanding public perceptions of wind energy. *Wind Energy* 2005;8:125–39.
- [36] Gunawan I, Redi AANP, Santosa AA, Maghfiroh MFN, Pandiyawargo AH, Kurniawan AC. Determinants of customer intentions to use electric vehicle in Indonesia: an integrated model analysis. *Sustainability* 2022;14:1972.
- [37] Jenkins LD, Dreyer SJ, Polis HJ, Beaver E, Kowalski AA, Linder HL, et al. Human dimensions of tidal energy: a review of theories and frameworks. *Renew Sustain Energy Rev* 2018;97:323–37.
- [38] Wilson C, Dowlatabadi H. Models of decision making and residential energy use. *Annu Rev Environ Resour* 2007;32:169–203.
- [39] Scovell MD. Explaining hydrogen energy technology acceptance: a critical review. *Int J Hydrogen Energy* 2022;47:10441–59.
- [40] Wang W, Li J, Li Y. Consumer willingness to purchase hydrogen fuel cell vehicles : A meta-analysis of the literature. *Int J Hydrogen Energy* 2024;50:1536–57.
- [41] Emodi NV, Lovell H, Levitt C, Franklin E. A systematic literature review of societal acceptance and stakeholders' perception of hydrogen technologies. *Int J Hydrogen Energy* 2021;46:30669–97.
- [42] Gordon JA, Balta-Ozkan N, Nabavi SA. Towards a unified theory of domestic hydrogen acceptance: an integrative, comparative review. *Int J Hydrogen Energy* 2024;56:498–524.
- [43] Gordon JA, Balta-Ozkan N, Nabavi SA. Price promises, trust deficits and energy justice: public perceptions of hydrogen homes. *Renewable Sustainable Energy Rev* 2023;188:113810.
- [44] Rogers EM. Diffusion of innovations. fourth ed. New York, NY: The Free Press; 1995.
- [45] Schwartz SH. Normative influences on altruism. *Adv Exp Soc Psychol* 1977;10:221–79.
- [46] Ajzen I. From intentions to actions: a theory of planned behavior. *Action Control* 1985:11–39.
- [47] Gordon JA. Perceived usefulness, perceived ease of use, and user acceptance of information technology. *MIS Q* 1989;13:319–40.
- [48] Slovic P. Perception of risk. *Science* 1987;236:280–5. <https://doi.org/10.1126/science.3563507>. 1979.
- [49] Fischhoff B. Managing risk perceptions. *Issues Sci Technol* 1985;2:83–96.
- [50] Komiak SYX, Benbasat I. The effects of personalization and familiarity on trust and adoption of recommendation agents. *MIS Q* 2006;30:941–60.
- [51] Gefen D, Karahanna E, Straub DW. Trust and tam in online shopping: AN integrated model. *MIS Q* 2003;27:51–90.
- [52] Frewer LJ, Howard JC, Hedderley D, Shepherd R. What determines trust in information about food-related risks? Underlying psychological constructs. *Risk Anal* 1999;16:473–86.
- [53] Wu IL, Chen JL. An extension of Trust and TAM model with TPB in the initial adoption of on-line tax: an empirical study. *Int J Hum Comput Stud* 2005;62:784–808.
- [54] Ross VL, Fielding KS, Louis WR. Social trust, risk perceptions and public acceptance of recycled water: testing a social-psychological model. *J Environ Manag* 2014;137:61–8.
- [55] Koufaris M. Applying the technology acceptance model and flow theory to online consumer behavior. *Inf Syst Res* 2002;13:205–23.
- [56] Venkatesh V. Determinants of perceived ease of use: integrating control, intrinsic motivation, and emotion into the technology acceptance model. *Inf Syst Res* 2000;11:342–65.
- [57] Mick DG, Fournier S. Paradoxes of technology: consumer cognizance, emotions, and coping strategies. *J Consum Res* 1998;25:123–43.
- [58] Wüstenhagen R, Wolsink M, Bürer MJ. Social acceptance of renewable energy innovation: an introduction to the concept. *Energy Pol* 2007;35:2683–91.
- [59] Upham P, Oltra C, Boso A. Towards a cross-paradigmatic framework of the social acceptance of energy systems. *Energy Res Social Sci* 2015;8:100–12.
- [60] Morrison M, Morgan MS. Models as mediating instruments. *Ideas Cont* 1999;52:10–37.
- [61] Gordon JA, Balta-Ozkan N, Haq A, Nabavi SA. Coupling green hydrogen production to community benefits: a pathway to social acceptance. *Energy Res Social Sci* 2024;110:103437.
- [62] Gordon JA, Balta-Ozkan N, Haq A, Nabavi SA. Heterogeneous preferences for living in a hydrogen home: an advanced multigroup analysis. *Sustain Energy Fuels* 2024;8:2061. 48.
- [63] Gordon JA, Balta-Ozkan N, Haq A, Nabavi SA. Necessary and sufficient conditions for deploying hydrogen homes: a consumer-oriented perspective. *Int J Hydrogen Energy* 2024;69:982–1021.
- [64] Gordon JA, Balta-Ozkan N, Haq A, Nabavi SA. Fuelling hydrogen futures: a trust-based model. *Energy Environ Sci* 2024 [Under review].
- [65] Bentsen HL, Skiple JK, Gregersen T, Derempouka E, Skjold T. In the green? Perceptions of hydrogen production methods among the Norwegian public. *Energy Res Social Sci* 2023;97:102985.
- [66] Yap J, McLellan B. Evaluating the attitudes of Japanese society towards the hydrogen economy: a comparative study of recent and past community surveys. *Int J Hydrogen Energy* 2024;54:66–83.
- [67] Häußermann JJ, Maier MJ, Kirsch TC, Kaiser S, Schraudner M. Social acceptance of green hydrogen in Germany: building trust through responsible innovation. *Energy Sustain Soc* 2023;13:1–19.
- [68] Beasy K, Lodewyckx S, Mattila P. Industry perceptions and community perspectives on advancing a hydrogen economy in Australia. *Int J Hydrogen Energy* 2023;48:8386–97.
- [69] Sovacool BK, Martiskainen M. Hot transformations: governing rapid and deep household heating transitions in China, Denmark, Finland and the United Kingdom. *Energy Pol* 2020;139:111330.
- [70] Gross R, Hanna R. Path dependency in provision of domestic heating. *Nat Energy* 2019;4:358–64.
- [71] Hannon MJ. Raising the temperature of the UK heat pump market: learning lessons from Finland. *Energy Pol* 2015;85:369–75.
- [72] Huang P, Broto VC, Liu Y. From “transitions in cities” to “transitions of cities”: the diffusion and adoption of solar hot water systems in urban China. *Energy Res Social Sci* 2018;36:156–64.
- [73] Arapostathis S, Pearson PJG, Foxon TJ. UK natural gas system integration in the making, 1960-2010: complexity, transitional uncertainties and uncertain transitions. *Environ Innov Soc Transit* 2014;11:87–102.

- [74] Arapostathis S, Carlsson-Hyslop A, Pearson PJG, Thornton J, Gradillas M, Laczay S, et al. Governing transitions: cases and insights from two periods in the history of the UK gas industry. *Energy Pol* 2013;52:25–44.
- [75] Sovacool BK. How long will it take? Conceptualizing the temporal dynamics of energy transitions. *Energy Res Social Sci* 2016;13:202–15.
- [76] Grubler A, Wilson C, Nemet G. Apples, oranges, and consistent comparisons of the temporal dynamics of energy transitions. *Energy Res Social Sci* 2016;22:18–25.
- [77] Odenweller A, Ueckerdt F, Nemet GF, Jensterle M, Luderer G. Probabilistic feasibility space of scaling up green hydrogen supply. *Nat Energy* 2022;7(9):854–65. 2022;7.
- [78] Gordon JA, Balta-Ozkan N, Nabavi SA. Socio-technical barriers to domestic hydrogen futures: repurposing pipelines, policies, and public perceptions. *Appl Energy* 2023;336:120850.
- [79] Cohen JJ, Reichl J, Schmidthaler M. Re-focussing research efforts on the public acceptance of energy infrastructure: a critical review. *Energy* 2014;76:4–9.
- [80] Krumm A, Süsser D, Blechinger P. Modelling social aspects of the energy transition: what is the current representation of social factors in energy models? *Energy* 2022;239:121706.
- [81] Bireselioglu ME, Solak B, Savas ZF. Unveiling resistance and opposition against low-carbon energy transitions: a comprehensive review. *Energy Res Social Sci* 2024;107:103354.
- [82] Westlake S, John CHD, Cox E. Perception spillover from fracking onto public perceptions of novel energy technologies. *Nat Energy* 2023;8:149–58.
- [83] Suskevičs M, Eiter S, Martinat S, Stober D, Vollmer E, de Boer CL, et al. Regional variation in public acceptance of wind energy development in Europe: what are the roles of planning procedures and participation? *Land Use Pol* 2019;81:311–23.
- [84] Reusswig F, Braun F, Heger I, Ludewig T, Eichenauer E, Lass W. Against the wind: local opposition to the German Energiewende. *Util Pol* 2016;41:214–27.
- [85] Susskind L, Chun J, Gant A, Hodgkins C, Cohen J, Lohmar S. Sources of opposition to renewable energy projects in the United States. *Energy Pol* 2022;165:112922.
- [86] van de Griff E, Cuppen E. Beyond the public in controversies: a systematic review on social opposition and renewable energy actors. *Energy Res Social Sci* 2022;91:102749.
- [87] Bolwig S, Bolkesjø TF, Klitkou A, Lund PD, Bergaentzle C, Borch K, et al. Climate-friendly but socially rejected energy-transition pathways: the integration of techno-economic and socio-technical approaches in the Nordic-Baltic region. *Energy Res Social Sci* 2020;67:101559.
- [88] Pye S, Li FGN, Price J, Fais B. Achieving net-zero emissions through the reframing of UK national targets in the post-Paris Agreement era. *Nat Energy* 2017;2(3):1–7. 2017;2.
- [89] Cherp A, Vinichenko V, Tosun J, Gordon JA, Jewell J. National growth dynamics of wind and solar power compared to the growth required for global climate targets. *Nat Energy* 2021;6:742–54.
- [90] Suzuki M, Jewell J, Cherp A. Have climate policies accelerated energy transitions? Historical evolution of electricity mix in the G7 and the EU compared to net-zero targets. *Energy Res Social Sci* 2023;106:103281.
- [91] Cossins-Smith A. Pragmatic and public opposition to hydrogen. *Power Technology*. <https://www.power-technology.com/features/public-opposition-to-hydrogen-pragmatic-problems-with-the-fuel/>. [Accessed 30 May 2024].
- [92] Rocha PA. UK shelves hydrogen town in blow for using fuel in home heating. *Bloomberg*; 2024. <https://www.bloomberg.com/news/articles/2024-05-09/uk-shelves-hydrogen-town-in-blow-for-using-fuel-in-home-heating?embedded-checkout=true>. [Accessed 11 May 2024].
- [93] Rosenow J. Is heating homes with hydrogen all but a pipe dream? An evidence review. *Joule* 2022;6:2225–8.
- [94] Eames M, McDowall W, Hodson M, Marvin S. Negotiating contested visions and place-specific expectations of the hydrogen economy. *Technol Anal Strateg Manag* 2006;18:361–74.
- [95] Eames M, McDowall W. Sustainability, foresight and contested futures: exploring visions and pathways in the transition to a hydrogen economy. *Technol Anal Strateg Manag* 2010;22:671–92.
- [96] Sovacool BK, Brossmann B. Symbolic convergence and the hydrogen economy. *Energy Pol* 2010;38:1999–2012.
- [97] Kern F, Schmelzle F, Hummel M. Hydrogen as a panacea for decarbonising everything? Exploring contested hydrogen pathways in Germany. *Environ Res Lett* 2023;18:114017.
- [98] Vezzoni R. How “clean” is the hydrogen economy? Tracing the connections between hydrogen and fossil fuels. *Environ Innov Soc Transit* 2024;50:100817.
- [99] HM government. UK hydrogen strategy. <https://www.gov.uk/government/publications/uk-hydrogen-strategy>; 2021.
- [100] The Committee on Climate Change. Hydrogen in a low-carbon economy. <https://www.theccc.org.uk/publication/hydrogen-in-a-low-carbon-economy/>; 2018.
- [101] The Committee on Climate Change. Next steps for UK heat policy. <https://www.theccc.org.uk/publication/next-steps-for-uk-heat-policy/>; 2016.
- [102] HM Government. Heat and buildings strategy. <https://www.gov.uk/government/publications/heat-and-buildings-strategy>; 2021.
- [103] Overland I. Russia's invasion of Ukraine: consequences for global decarbonization. *Russian Anal Dig* 2022;284:2–5.
- [104] Zhou XY, Lu G, Xu Z, Yan X, Khu ST, Yang J, et al. Influence of Russia-Ukraine war on the global energy and food security. *Resour Conserv Recycl* 2023;188:106657.
- [105] HM Government. British Energy Security Strategy: secure, clean and affordable British energy for the long term. <https://www.gov.uk/government/publications/british-energy-security-strategy>; 2022.
- [106] Gas Cadent. Hydrogen heating village trial stage 2: submission application. <https://cadentgas.com/ngdwsdev/media/FROG/Whitby-Hydrogen-Village-Submission-Application.pdf>; 2023.
- [107] Cadent Gas. Why 2,000 homes in Ellesmere Port could help solve our climate crisis. <https://cadentgas.com/news-media/news/may-2022/ellesmere-port-home-s-could-help-climate-crisis>. [Accessed 3 June 2022].
- [108] Cadent Gas. The UK's first homes with appliances fuelled entirely by hydrogen have been officially opened by Energy Minister. Anne-Marie Trevelyan 2021. <https://cadentgas.com/news-media/news/july-2021/first-hydrogen-homes-open-to-the-public>. [Accessed 28 July 2022].
- [109] Mavrokefalidis D. Hydrogen village trial in Whitby rejected. *Energy Live News* 2023. <https://www.energylivenews.com/2023/07/11/hydrogen-village-trial-in-whitby-rejected/>. [Accessed 17 July 2023].
- [110] Jasi A. UK's Redcar 'hydrogen village' trial cancelled due to insufficient feedstock supply. *Chem Eng Lond* 2023. <https://www.thechemicalengineer.com/news/uk-s-redcar-hydrogen-village-trial-cancelled-due-to-insufficient-feedstock-supply/>. [Accessed 17 December 2023].
- [111] National Infrastructure Commission. Tech annex: Hydrogen heating 2023. <https://nic.org.uk/studies-reports/national-infrastructure-assessment/second-nia/hydrogen-for-heat-annex/>. [Accessed 17 March 2024].
- [112] Department for Energy Security & Net Zero. Hydrogen heating: overview 2024. <https://www.gov.uk/government/publications/hydrogen-heating-overview/hydrogen-heating-overview-2>. [Accessed 15 April 2024].
- [113] UK's only green hydrogen heating trial delayed by up to a year amid “supply-chain and procurement challenges” | Hydrogen Insight n.d. <https://www.hydrogeninsight.com/policy/uks-only-green-hydrogen-heating-trial-delayed-by-up-to-a-year-amid-supply-chain-and-procurement-challenges/2-1-1630848>. [Accessed 3 June 2024].
- [114] “No place in our homes” | Hydrogen blends leak twice as much in household cookers compared to gas: report | Hydrogen Insight n.d. <https://www.hydrogeninsight.com/policy/no-place-in-our-homes-hydrogen-blends-leak-twice-as-much-in-household-cookers-compared-to-gas-report/2-1-1628681> (accessed June 3, 2024).
- [115] Rosenow J. A meta-review of 54 studies on hydrogen heating. *Cell Rep Sustain* 2024;1:100010.
- [116] Lamb N, Elmes D. Increasing heat pump adoption: analysing multiple perspectives on preparing homes for heat pumps in the UK. *Carbon Neutra* 2024;3:10.
- [117] Sovacool BK, Kivimaa P, Hielscher S, Jenkins K. Vulnerability and resistance in the United Kingdom's smart meter transition. *Energy Pol* 2017;109:767–81.
- [118] Salite D, Miao Y, Turner E, Feng Y. Assessing the adoption of sustainable heating technologies in the United Kingdom – a case study of socioeconomically deprived neighbourhoods of Nottingham city. *Technol Soc* 2024;77:102508.
- [119] Buchanan K, Banks N, Preston I, Russo R. The British public's perception of the UK smart metering initiative: threats and opportunities. *Energy Pol* 2016;91:87–97.
- [120] Gordon JA, Balta-Ozkan N, Nabavi SA. Beyond the triangle of renewable energy acceptance: the five dimensions of domestic hydrogen acceptance. *Appl Energy* 2022;324:119715.
- [121] Batel S. Research on the social acceptance of renewable energy technologies: past, present and future. *Energy Res Social Sci* 2020;68:101544.
- [122] De Groot JIM, Steg L, Poortinga W. Values, perceived risks and benefits, and acceptability of nuclear energy. *Risk Anal* 2013;33:307–17.
- [123] Nohrstedt D. External shocks and policy change: three Mile Island and Swedish nuclear energy policy. *J Eur Publ Pol* 2005;12:1041–59.
- [124] Contu D, Strazzera E, Mourato S. Modeling individual preferences for energy sources: the case of IV generation nuclear energy in Italy. *Ecol Econ* 2016;127:37–58.
- [125] McCauley D, Brown A, Rehner R, Heffron R, van de Graaff S. Energy justice and policy change: an historical political analysis of the German nuclear phase-out. *Appl Energy* 2018;228:317–23.
- [126] Brutschin E, Cherp A, Jewell J. Failing the formative phase: the global diffusion of nuclear power is limited by national markets. *Energy Res Social Sci* 2021;80:102221.
- [127] Cherp A, Vinichenko V, Jewell J, Brutschin E, Sovacool B. Integrating techno-economic, socio-technical and political perspectives on national energy transitions: a meta-theoretical framework. *Energy Res Social Sci* 2018;37:175–90.
- [128] Gordon JA, Balta-Ozkan N, Sali Nabavi. Divergent consumer preferences and visions for cooking and heating technologies in the United Kingdom: make our homes clean, safe, warm and smart. *Energy Res Social Sci* 2023;104:103204.
- [129] Gordon JA, Balta-Ozkan N, Nabavi SA. Gauging public perceptions of blue and green hydrogen futures: is the twin-track approach compatible with hydrogen acceptance? *Int J Hydrogen Energy* 2024;49:75–104.
- [130] Gordon JA, Balta-Ozkan N, Haq A, Nabavi SA. Necessary and sufficient conditions for deploying hydrogen homes: a consumer-orientated perspective. *Int J Hydrogen Energy* 2024;49:982–1021.
- [131] Montijn-Dorgelo FNH, Midden CJH. The role of negative associations and trust in risk perception of new hydrogen systems. *J Risk Res* 2008;11:659–71.
- [132] Oltra C, Dütschke E, Sala R, Schneider U, Upham P. The public acceptance of hydrogen fuel cell applications in Europe. *Rev Int Sociol* 2017;75:e076.
- [133] Bögel P, Oltra C, Sala R, Lores M, Upham P, Dütschke E, et al. The role of attitudes in technology acceptance management: reflections on the case of hydrogen fuel cells in Europe. *J Clean Prod* 2018;188:125–35.

- [134] Martin V, Ashworth P, Petrova S, Wade B, Witt K, Clarke E. Public perceptions of hydrogen: 2021 national survey results. *Future Fuels* 2021;CRC. <https://espace.library.uq.edu.au/view/UQ:f25a2cc>.
- [135] Lozano LL, Bharadwaj B, de Sales A, Kambo A, Ashworth P. Societal acceptance of hydrogen for domestic and export applications in Australia. *Int J Hydrogen Energy* 2022;47:28806–18.
- [136] Zimmer R, Welke J. Let's go green with hydrogen! the general public's perspective. *Int J Hydrogen Energy* 2012;37:17502–8.
- [137] Smith C, Bucke C, van der Horst D. Green hydrogen powering sustainable festivals: public perceptions of generators, production and ownership. *Int J Hydrogen Energy* 2023;48:8370–85.
- [138] Gordon JA, Balta-Ozkan N, Nabavi A. Green and blue hydrogen futures: gauging public knowledge, awareness, perceptions and preferences. *Int J Hydrogen Energy* 2023;49(Part D):75–104.
- [139] Apostolou D, Welcher SN. Prospects of the hydrogen-based mobility in the private vehicle market. A social perspective in Denmark. *Int J Hydrogen Energy* 2021;46:6885–900.
- [140] Harichandan S, Kar SK, Bansal R, Mishra SK. Achieving sustainable development goals through adoption of hydrogen fuel cell vehicles in India: an empirical analysis. *Int J Hydrogen Energy* 2023;48:4845–59.
- [141] Hienuki S, Hirayama Y, Shibutani T, Sakamoto J, Nakayama J, Miyake A. How knowledge about or experience with hydrogen fueling stations improves their public acceptance. *Sustainability* 2019;11:6339.
- [142] Ono K, Tsunemi K. Identification of public acceptance factors with risk perception scales on hydrogen fueling stations in Japan. *Int J Hydrogen Energy* 2017;42:10697–707.
- [143] Gordon JA, Balta-Ozkan N, Nabavi SA. Divergent consumer preferences and visions for cooking and heating technologies in the United Kingdom: make our homes clean, safe, warm and smart. *Energy Res Social Sci* 2023;104:103204.
- [144] Scott M, Powells G. Towards a new social science research agenda for hydrogen transitions: social practices, energy justice, and place attachment. *Energy Res Social Sci* 2020;61:101346.
- [145] Scott M, Powells G. Sensing hydrogen transitions in homes through social practices: cooking, heating, and the decomposition of demand. *Int J Hydrogen Energy* 2020;45:3870–82.
- [146] Gray D, Snodin H, Bullen A. Exploring the evidence on potential issues associated with trialling hydrogen heating in communities: a literature review and focus group study. Department for Business, Energy & Industrial Strategy; 2019. BEIS Research Paper Number 2020/018, <https://www.gov.uk/government/publications/exploring-the-evidence-on-issues-associated-with-trialling-hydrogen-heating>.
- [147] Dillman KJ, Heinonen J. A 'just' hydrogen economy: a normative energy justice assessment of the hydrogen economy. *Renew Sustain Energy Rev* 2022;167:112648.
- [148] Yap J, McLellan B. Evaluating the attitudes of Japanese society towards the hydrogen economy: a comparative study of recent and past community surveys. *Int J Hydrogen Energy* 2023;54:66–83.
- [149] Lambert V, Ashworth P. The Australian public's perception of hydrogen for energy. Report for the Australian Government's Renewable Energy Agency; 2018. <https://arena.gov.au/knowledge-bank/the-australian-publics-perception-of-hydrogen-for-energy/>.
- [150] Lozano LL, Bharadwaj B, de Sales A, Kambo A, Ashworth P. Societal acceptance of hydrogen for domestic and export applications in Australia. *Int J Hydrogen Energy* 2022;47:28806–18.
- [151] Scott M, Powells G. Towards a new social science research agenda for hydrogen transitions: social practices, energy justice, and place attachment. *Energy Res Social Sci* 2020;61:101346.
- [152] Kar SK, Bansal R, Harichandan S. An empirical study on intention to use hydrogen fuel cell vehicles in India. *Int J Hydrogen Energy* 2022;47:19999–20015.
- [153] Emmerich P, Hüllemeier AG, Jendryczko D, Baumann MJ, Weil M, Baur D. Public acceptance of emerging energy technologies in context of the German energy transition. *Energy Pol* 2020;142:111516.
- [154] Dumbrell NP, Wheeler SA, Zuo A, Adamson D. Public willingness to make trade-offs in the development of a hydrogen industry in Australia. *Energy Pol* 2022;165:112987.
- [155] Huijts NMA. The emotional dimensions of energy projects: anger, fear, joy and pride about the first hydrogen fuel station in The Netherlands. *Energy Res Social Sci* 2018;44:138–45.
- [156] Fylan F, Fletcher M, Christmas S. H21: public perceptions of converting the gas network to hydrogen. Leeds Beckett University; 2020. <https://together.northernngasnetworks.co.uk/events/h21-public-perceptions-of-hydrogen/>.
- [157] Sandri O, Holdsworth S, Hayes J, Willand N, Moore T. Hydrogen for all? Household energy vulnerability and the transition to hydrogen in Australia. *Energy Res Social Sci* 2021;79:102179.
- [158] Scott M, Powells G. Blended hydrogen: the UK public's perspective. Newcastle University School of Geography, Politics and Sociology; 2019. <https://www.ncl.ac.uk/cesi/research/papers/publications/blendedhydrogentheukpublicperspective.html>.
- [159] Martiskainen M, Sovacool BK. Mixed feelings: a review and research agenda for emotions in sustainability transitions. *Environ Innov Soc Transit* 2021;40:609–24.
- [160] Huijts NMA, Midden CJH, Meijnders AL. Social acceptance of carbon dioxide storage. *Energy Pol* 2007;35:2780–9.
- [161] Contzen N, Handreke AV, Perlaviciute G, Steg L. Emotions towards a mandatory adoption of renewable energy innovations: the role of psychological reactance and egoistic and biospheric values. *Energy Res Social Sci* 2021;80:102232.
- [162] Contzen N, Perlaviciute G, Sadat-Razavi P, Steg L. Emotions toward sustainable innovations: a matter of value congruence. *Front Psychol* 2021;12:661314.
- [163] Van Alstine J, Bastin C. Establishing the UK hydrogen corridor: socio-economic, environmental, and regulatory issues. University of Leeds; 2019. <https://eprints.whiterose.ac.uk/163121/>.
- [164] Gordon JA, Balta-Ozkan N, Nabavi SA. Homes of the future: unpacking public perceptions to power the domestic hydrogen transition. *Renew Sustain Energy Rev* 2022;164:112481.
- [165] Gordon JA, Balta-Ozkan N, Nabavi SA. Hopes and fears for a sustainable energy future: exploring the hydrogen acceptance matrix. *Int J Hydrogen Energy* 2024;60:1170–91.
- [166] Legault L, Bird S, Heintzelman MD. Pro-environmental, prosocial, pro-self, or does it depend? A more nuanced understanding of the motivations underlying residential solar panel adoption. *Energy Res Social Sci* 2024;111:103481.
- [167] Hair Jr JF, Matthews LM, Matthews RL, Sarstedt M. PLS-SEM or CB-SEM: updated guidelines on which method to use. *Intern J Multiva Data Analy* 2017;1:107–23.
- [168] Lowry PB, Gaskin J. Partial least squares (PLS) structural equation modeling (SEM) for building and testing behavioral causal theory: when to choose it and how to use it. *IEEE Trans Prof Commun* 2014;57:123–46.
- [169] Dennis Cook R, Forzani L. On the role of partial least squares in path analysis for the social sciences. *J Bus Res* 2023;167:114132.
- [170] Shmueli G, Sarstedt M, Hair JF, Cheah JH, Ting H, Vaithilingam S, et al. Predictive model assessment in PLS-SEM: guidelines for using PLSpredict. *Eur J Market* 2019;53:2322–47.
- [171] Sarstedt M, Ringle CM, Henseler J, Hair JF. On the emancipation of PLS-SEM: a commentary on Rigdon. *Long Range Plan* 2014;47:154–60.
- [172] Chin W, Cheah JH, Liu Y, Ting H, Lim XJ, Cham TH. Demystifying the role of causal-predictive modeling using partial least squares structural equation modeling in information systems research. *Ind Manag Data Syst* 2020;120:2161–209.
- [173] Liengaard BD, Sharma PN, Hult GTM, Jensen MB, Sarstedt M, Hair JF, et al. Prediction: coveted, yet forsaken? Introducing a cross-validated predictive ability test in partial least squares path modeling. *Decis Sci J* 2021;52:362–92.
- [174] Sarstedt M, Schwaiger M, Ringle CM. Do we fully understand the critical success factors of customer satisfaction with industrial goods?—extending Festge and Schwaiger's model to account for unobserved heterogeneity. *Article J Busi Market Manag* 2012;3:185–206.
- [175] Basco R, Hair JF, Ringle CM, Sarstedt M. Advancing family business research through modeling nonlinear relationships: comparing PLS-SEM and multiple regression. *J Family Bus Strategy* 2022;13:100457.
- [176] Richter NF, Sinkovics RR, Ringle CM, Schlögel C. A critical look at the use of SEM in international business research. *Int Market Res* 2016;33:376–404.
- [177] Guenther P, Guenther M, Ringle CM, Zafarian G, Cartwright S. Improving PLS-SEM use for business marketing research. *Ind Market Manag* 2023;111:127–42.
- [178] Alkaws GA, Ali N, Baashar Y. An empirical study of the acceptance of IoT-based smart meter in Malaysia: the effect of electricity-saving knowledge and environmental awareness. *IEEE Access* 2020;8:42794–804.
- [179] Shuhaiber A, Mashal I. Understanding users' acceptance of smart homes. *Technol Soc* 2019;58:101110.
- [180] Ferreira L, Oliveira T, Neves C. Consumer's intention to use and recommend smart home technologies: the role of environmental awareness. *Energy* 2023;263:125814.
- [181] Yin YC, Ahmed J, Nee AYH, Hoe OK. The rural consumer adoption of sustainable energy: a PLS-SEM-ANN approach of conceptual model development and cross-country validation of Pakistan and Malaysia. *Environ Sci Pollut Control Ser* 2022 30:3 2022;30:5881–902.
- [182] Ali S, Poulouva P, Akbar A, Javed H, Danish M. Determining the influencing factors in the adoption of solar photovoltaic technology in Pakistan: a decomposed technology acceptance model approach. *Economies* 2020;8:108.
- [183] Neves C, Oliveira T. Drivers of consumers' change to an energy-efficient heating appliance (EEHA) in households: evidence from five European countries. *Appl Energy* 2021;298:117165.
- [184] Kang MJ, Park H. Impact of experience on government policy toward acceptance of hydrogen fuel cell vehicles in Korea. *Energy Pol* 2011;39:3465–75.
- [185] Ringle CM, Wende S, Becker J-M. SmartPLS 4 oststeinbek. 2022. <https://www.smartpls.com/documentation/algorithms-and-techniques/higher-order/>. [Accessed 30 May 2023].
- [186] Hair JF, Risher JJ, Sarstedt M, Ringle CM. When to use and how to report the results of PLS-SEM. *Eur Bus Rev* 2019;31:2–24.
- [187] Kock N, Hadaya P. Minimum sample size estimation in PLS-SEM: the inverse square root and gamma-exponential methods. *Inf Syst J* 2018;28:227–61.
- [188] Beran TN, Violato C. Structural equation modeling in medical research: a primer. *BMC Res Notes* 2010;3:1–10.
- [189] Memon MA, Thuramamy R, Cheah J-H, Ting H, Chuah F, Cham TH. Addressing common method bias, operationalization, sampling, and data collection issues in quantitative research: review and recommendations. *J Appl Struct Equat Model* 2023;7:1–14.
- [190] Faul F, Erdfelder E, Lang AG, Buchner A. G* Power 3: a flexible statistical power analysis program for the social, behavioral, and biomedical sciences. *Behav Res Methods* 2007;39:175–91.
- [191] Erdfelder E, Faul F, Buchner A, Lang AG. Statistical power analyses using G*Power 3.1: tests for correlation and regression analyses. *Behav Res Methods* 2009;41:1149–60.
- [192] Wolf EJ, Harrington KM, Clark SL, Miller MW. Sample size requirements for structural equation models: an evaluation of power, bias, and solution propriety. *Educ Psychol Meas* 2013;73:913–34.
- [193] Gorrell G, Ford N, Madden A, Holdridge P, Eaglestone B. Countering method bias in questionnaire-based user studies. *J Doc* 2011;67:507–24.

- [194] Ringle CM, Sarstedt M. Gain more insight from your PLS-SEM results: the importance-performance map analysis. *Ind Manag Data Syst* 2016;116:1865–86.
- [195] Richter NF, Hauff S, Kolev AE, Schubring S. Dataset on an extended technology acceptance model: a combined application of PLS-SEM and NCA. *Data Brief* 2023; 48:109190.
- [196] Streukens S, Leroi-Werelds S, Willems K. Dealing with nonlinearity in importance-performance map analysis (IPMA): an integrative framework in a PLS-SEM context. In: Latan H, Noonan R, editors. *Partial least squares path modeling: basic concepts, methodological issues and applications*. Springer; 2017. p. 367–403.
- [197] Rigdon E, Ringle CM, Sarstedt M, Siegfried Gudergan S. Assessing heterogeneity in customer satisfaction studies: across industry similarities and within industry differences. *Measure Res Methods Intern Marke* 2011;22:169–94.
- [198] Hair Jr JF, Sarstedt M, Pieper TM, Ringle CM. The use of partial least squares structural equation modeling in strategic management research: a review of past practices and recommendations for future applications. *Long Range Plan* 2012; 45:320–40.
- [199] Wong GZ, Wong KH, Lau TC, Lee JH, Kok YH. Study of intention to use renewable energy technology in Malaysia using TAM and TPB. *Renew Energy* 2024;221: 119787.
- [200] Agarwal R, Bhaduria A, Swami S, Rajwanshi R. Factors influence or inhibit the purchase intention towards rooftop solar: using structural equation modeling and importance performance map analysis approach. *J Clean Prod* 2023;410.
- [201] Bamidele RO, Oztüren A, Haktanir M, Ogunmukun OA. Realizing green airport performance through green management intransigence, Airport reputation, biospheric value, and eco-Design. *Sustainability* 2023;15:2475.
- [202] Höck C, Ringle CM, Sarstedt M. Management of multi-purpose stadiums: importance and performance measurement of service interfaces. *Int J Serv Technol Manag* 2010;14:188–207.
- [203] Brosch T, Patel MK, Sander D. Affective influences on energy-related decisions and behaviors. *Front Energy Res* 2014;2:11.
- [204] Hecher M, Hatzl S, Knoeri C, Posch A. The trigger matters: the decision-making process for heating systems in the residential building sector. *Energy Pol* 2017; 102:288–306.
- [205] Elmustapha H, Hoppe T, Bressers H. Consumer renewable energy technology adoption decision-making; comparing models on perceived attributes and attitudinal constructs in the case of solar water heaters in Lebanon. *J Clean Prod* 2018;172:347–57.
- [206] Jabeen G, Yan Q, Ahmad M, Fatima N, Qamar S. Consumers' intention-based influence factors of renewable power generation technology utilization: a structural equation modeling approach. *J Clean Prod* 2019;237:117737.
- [207] Chadwick K, Russell-Bennett R, Biddle N. The role of human influences on adoption and rejection of energy technology: a systematized critical review of the literature on household energy transitions. *Energy Res Social Sci* 2022;89: 102528.
- [208] Venkatesh V, Thong JYL, Xu X. Unified theory of acceptance and use of technology: a synthesis and the road ahead. *J Assoc Inf Syst Online* 2016;17: 328–76.
- [209] Kumar P, Caggiano H, Cuite C, Andrews CJ, Felder FA, Shwom R, et al. Behaving or not? Explaining energy conservation via identity, values, and awareness in U.S. suburban homes. *Energy Res Social Sci* 2022;92:102805.
- [210] Frederiks ER, Stenner K, Hobman EV. The socio-demographic and psychological predictors of residential energy consumption: a comprehensive review. *Energies* 2015;8:573–609.
- [211] Hobman EV, Ashworth P. Public support for energy sources and related technologies: the impact of simple information provision. *Energy Pol* 2013;63: 862–9.
- [212] Al-Emran M. Beyond technology acceptance: development and evaluation of technology-environmental, economic, and social sustainability theory. *Technol Soc* 2023;75:102383.
- [213] Sovacool BK. Experts, theories, and electric mobility transitions: toward an integrated conceptual framework for the adoption of electric vehicles. *Energy Res Social Sci* 2017;27:78–95.
- [214] Ettema D, Gärling T, Eriksson L, Friman M, Olsson LE, Fujii S. Satisfaction with travel and subjective well-being: development and test of a measurement tool. *Transport Res F Traffic Psychol Behav* 2011;14:167–75.
- [215] Friman M, Fujii S, Ettema D, Gärling T, Olsson LE. Psychometric analysis of the satisfaction with travel scale. *Transport Res Part A Policy Pract* 2013;48:132–45.
- [216] Son W, Lee S, Woo JR. Community acceptance of hydrogen power plant projects: the case of South Korea. *Renew Sustain Energy Rev* 2023;187:113778.
- [217] Wong KKK. Partial least squares structural equation modeling (PLS-SEM) techniques using SmartPLS. *Market Bull* 2013;24:1–32.
- [218] Sarstedt M, Hair JF, Ringle CM, Thiele KO, Gudergan SP. Estimation issues with PLS and CBSEM: where the bias lies. *J Bus Res* 2016;69:3998–4010.
- [219] Sarstedt M, Hair JF, Cheah JH, Becker JM, Ringle CM. How to specify, estimate, and validate higher-order constructs in PLS-SEM. *Australas Market J* 2019;27: 197–211.
- [220] Lee J, Reiner DM. Determinants of public preferences on low-carbon energy sources: evidence from the United Kingdom. *Energy* 2023;284:128704.
- [221] Sonnberger M, Ruddat M. Local and socio-political acceptance of wind farms in Germany. *Technol Soc* 2017;51:56–65.
- [222] Lange M, Cummins V. Managing stakeholder perception and engagement for marine energy transitions in a decarbonising world. *Renew Sustain Energy Rev* 2021;152:111740.
- [223] Choi YS, Han EO, Lee SK. Influence of nuclear power perception by leadership groups of South Korea on nuclear power policy. *Energy Strategy Rev* 2021;35: 100654.
- [224] Gupta K, Jenkins-Smith H, Ripberger J, Silva C, Fox A, Livingston W. Americans' views of fusion energy: implications for sustainable public support. *Fusion Sci Technol* 2024:1–17.
- [225] Kitt S, Axsen J, Long Z, Rhodes E. The role of trust in citizen acceptance of climate policy: comparing perceptions of government competence, integrity and value similarity. *Ecol Econ* 2021;183:106958.
- [226] Donnison CL, Trdicova K, Mohr A, Taylor G. A net-zero storyline for success? News media analysis of the social legitimacy of bioenergy with carbon capture and storage in the United Kingdom. *Energy Res Social Sci* 2023;102:103153.
- [227] Yang L, Zhang X, McAlinden KJ. The effect of trust on people's acceptance of CCS (carbon capture and storage) technologies: evidence from a survey in the People's Republic of China. *Energy* 2016;96:69–79.
- [228] Huijts NMA, Molin EJE, van Wee B. Hydrogen fuel station acceptance: a structural equation model based on the technology acceptance framework. *J Environ Psychol* 2014;38:153–66.
- [229] Baur D, Emmerich P, Baumann MJ, Weil M. Assessing the social acceptance of key technologies for the German energy transition. *Energy Sustain Soc* 2022;12:1–16.
- [230] Schönauer AL, Glanz S. Hydrogen in future energy systems: social acceptance of the technology and its large-scale infrastructure. *Int J Hydrogen Energy* 2022;47: 12251–63.
- [231] Ashworth P, Witt K, Ferguson M, Sehic S. Developing community trust in hydrogen. The University of Queensland, School of Chemical Engineering; 2019. <https://espace.library.uq.edu.au/view/UQ:4ea6a57>.
- [232] Macht J, Klink-Lehmann J, Hartmann M. Don't forget the locals: understanding citizens' acceptance of bio-based technologies. *Technol Soc* 2023;74:102318.
- [233] Midden CJH, Huijts NMA. The role of trust in the affective evaluation of novel risks: the case of CO₂ storage. *Risk Anal* 2009;29:743–51.
- [234] Huijts NMA, Midden CJH, Meijnders AL. Social acceptance of carbon dioxide storage. *Energy Pol* 2007;35:2780–9.
- [235] Bronfman NC, Jiménez RB, Arévalo PC, Cifuentes LA. Understanding social acceptance of electricity generation sources. *Energy Pol* 2012;46:246–52.
- [236] Park E, Ohm JY. Factors influencing the public intention to use renewable energy technologies in South Korea: effects of the Fukushima nuclear accident. *Energy Pol* 2014;65:198–211.
- [237] Siegrist M, Cvetkovich G, Roth C. Salient value similarity, social trust, and risk/benefit perception. *Risk Anal* 2000;20:353–62.
- [238] Xiao Q, Liu H, Feldman MW. How does trust affect acceptance of a nuclear power plant (NPP): a survey among people living with Qinshan NPP in China. *PLoS One* 2017;12:e0187941.
- [239] Rosenow J, Lowes R. Will blue hydrogen lock us into fossil fuels forever? *One Earth* 2022;4:1527–9.
- [240] Hoffmann C, Ziemann N, Penske F, Müsgens F. The value of secure electricity supply for increasing acceptance of green hydrogen: first experimental evidence from the virtual reality lab. *International conference on the European energy market, EEM, 2023– June*. IEEE Computer Society; 2023.
- [241] Mouli-Castillo J, Haszeldine SR, Kinsella K, Wheeldon M, McIntosh A. A quantitative risk assessment of a domestic property connected to a hydrogen distribution network. *Int J Hydrogen Energy* 2021;46:16217–31.
- [242] Azadnia AH, McDavid C, Andwari AM, Hosseini SE. Green hydrogen supply chain risk analysis: a European hard-to-abate sectors perspective. *Renew Sustain Energy Rev* 2023;182:113371.
- [243] Rigas F, Amyotte P. Myths and facts about hydrogen hazards. *Chem Eng Trans* 2013;31(Italian Association of Chemical Engineering - AIDIC):913–8.
- [244] Rosen MA, Koohi-Fayegh S. The prospects for hydrogen as an energy carrier: an overview of hydrogen energy and hydrogen energy systems. *Energy Ecol Environ* 2016;1:10–29.
- [245] Kuzemko C, Bradshaw M, Bridge G, Goldthau A, Jewell J, Overland I, et al. Covid-19 and the politics of sustainable energy transitions. *Energy Res Social Sci* 2020; 68:101685.
- [246] Liadze I, Macchiarelli C, Mortimer-Lee P, Sanchez Juanino P. Economic costs of the Russia-Ukraine war. *World Econ* 2023;46:874–86.
- [247] Huang Q. The pandemic and the transformation of liberal international order. *J Chin Polit Sci* 2021;26:1–26.
- [248] Kutlay M, Öniş Z. Liberal democracy on the edge? Anxieties in a shifting global (dis)order. *Alternatives* 2023;48:20–37.
- [249] Sovacool BK, Upham P, Martiskainen M, Jenkins KEH, Torres Contreras GA, Simcock N. Policy prescriptions to address energy and transport poverty in the United Kingdom. *Nat Energy* 2023;8:273–83.
- [250] Michelsen CC, Madlener R. Motivational factors influencing the homeowners' decisions between residential heating systems: an empirical analysis for Germany. *Energy Pol* 2013;57:221–33.
- [251] Michelsen CC, Madlener R. Homeowners' preferences for adopting innovative residential heating systems: a discrete choice analysis for Germany. *Energy Econ* 2012;34:1271–83.
- [252] Chou JS, Yutami IGAN. Smart meter adoption and deployment strategy for residential buildings in Indonesia. *Appl Energy* 2014;128:336–49.
- [253] Davis FD. Perceived usefulness, perceived ease of use, and user acceptance of information technology. *MIS Q* 1989;13:319–39.
- [254] Conner M, Norman P. Understanding the intention-behavior gap: the role of intention strength. *Front Psychol* 2022;13:923464.
- [255] Sultan P, Tarafder T, Pearson D, Henrys KJ. Intention-behaviour gap and perceived behavioural control-behaviour gap in theory of planned behaviour: moderating roles of communication, satisfaction and trust in organic food consumption. *Food Qual Prefer* 2020;81:103838.

- [256] Kowalska-Pyzalska A. What makes consumers adopt to innovative energy services in the energy market? A review of incentives and barriers. *Renew Sustain Energy Rev* 2018;82:3570–81.
- [257] Hai MA, Moula MME, Sepälä U. Results of intention-behaviour gap for solar energy in regular residential buildings in Finland. *Intern J Sustain Built Environ* 2017;6:317–29.
- [258] Smith C, Mouli-Castillo J, van der Horst D, Haszeldine S, Lane M. Towards a 100% hydrogen domestic gas network: regulatory and commercial barriers to the first demonstrator project in the United Kingdom. *Int J Hydrogen Energy* 2022;47:23071–83.
- [259] Department of Business. Energy & industrial strategy. BEIS public attitudes tracker: energy infrastructure and energy sources, winter 2022. <https://www.gov.uk/government/collections/public-attitudes-tracking-survey>; 2023.
- [260] Damette O, Buckley P, Agnoletti M-F, Martin AA. A prospective study on consumer preferences for hydrogen energy for residential applications: a choice experiment. https://papers.ssrn.com/sol3/papers.cfm?abstract_id=4024061; 2022.
- [261] Sovacool BK, Cabeza LF, Pisello AL, Fronzetti Colladon A, Larjani HM, Dawoud B, et al. Decarbonizing household heating: reviewing demographics, geography and low-carbon practices and preferences in five European countries. *Renew Sustain Energy Rev* 2021;139:110703.
- [262] Williams H, Lohmann T, Foster S, Morrell G. Public acceptability of the use of hydrogen for heating and cooking in the home: results from qualitative and quantitative research in UK. London, <https://www.theccc.org.uk/wp-content/uploads/2018/11/Public-acceptability-of-hydrogen-in-the-home-Full-report.pdf>; 2018.
- [263] Rai V, Beck AL. Public perceptions and information gaps in solar energy in Texas. *Environ Res Lett* 2015;10:07411.
- [264] Scheller F, Morrissey K, Neuhoof K, Keles D. Green or greedy: the relationship between perceived benefits and homeowners' intention to adopt residential low-carbon technologies. *Energy Res Social Sci* 2024;108:103388.
- [265] Department of Business. Energy & industrial strategy. BEIS public attitudes tracker: heat and energy in the home, winter 2022. <https://www.gov.uk/government/statistics/beis-public-attitudes-tracker-winter-2022>; 2022.
- [266] Thomas G, Pidgeon N, Henwood K. Hydrogen, a less disruptive pathway for domestic heat? Exploratory findings from public perceptions research. *Cleaner Produ Lett* 2023;5:100047.
- [267] Olson-Hazboun SK. "Why are we being punished and they are being rewarded?" views on renewable energy in fossil fuels-based communities of the U.S. west. *Extr Ind Soc* 2018;5:366–74.
- [268] Ambrosio-Albalá P, Upham P, Bale CSE. Purely ornamental? Public perceptions of distributed energy storage in the United Kingdom. *Energy Res Social Sci* 2019;48:139–50.
- [269] Perlaviciute G, Steg L, Contzen N, Roeser S, Huijts N. Emotional responses to energy projects: insights for responsible decision making in a sustainable energy transition. *Sustainability* 2018;10:2526.
- [270] Cousse J, Wüstenhagen R, Schneider N. Mixed feelings on wind energy: affective imagery and local concern driving social acceptance in Switzerland. *Energy Res Social Sci* 2020;70:101676.
- [271] Huijts NMA, Contzen N, Roeser S. Unequal means more unfair means more negative emotions? Ethical concerns and emotions about an unequal distribution of negative outcomes of a local energy project. *Energy Pol* 2022;165:112963.
- [272] Cousse J. Still in love with solar energy? Installation size, affect, and the social acceptance of renewable energy technologies. *Renew Sustain Energy Rev* 2021;145:111107.
- [273] Rincón-Rubio AG, Cedano-Villavicencio KG. Emotional energy communities: centering emotions and feelings within energy transitions in southern Mexico. *Energy Res Social Sci* 2023;98:103014.
- [274] Buah E, Linnanen L, Wu H. Emotional responses to energy projects: a new method for modeling and prediction beyond self-reported emotion measure. *Energy* 2020;190:116210.
- [275] Truelove HB. Energy source perceptions and policy support: image associations, emotional evaluations, and cognitive beliefs. *Energy Pol* 2012;45:478–89.
- [276] Ono K, Kato E, Tsunemi K. Construction of a structural equation model to identify public acceptance factors for hydrogen refueling stations under the provision of risk and safety information. *Int J Hydrogen Energy* 2022;47:31974–84.
- [277] Le TT, Sharma P, Bora BJ, Tran VD, Truong TH, Le HC, et al. Fueling the future: a comprehensive review of hydrogen energy systems and their challenges. *Int J Hydrogen Energy* 2024;54:791–816.
- [278] Yap J, McLellan B. Exploring transitions to a hydrogen economy: quantitative insights from an expert survey. *Int J Hydrogen Energy* 2024;66:371–86.
- [279] Hair Jr JF, Howard MC, Nitzl C. Assessing measurement model quality in PLS-SEM using confirmatory composite analysis. *J Bus Res* 2020;109:101–10.
- [280] Hulland J. Use of partial least squares (PLS) in strategic management research: a review of four recent studies. *Strat Manag J* 1999;20(2):195–204. 20:195–204.
- [281] Ravand H, Baghaei P. Partial least squares structural equation modeling with R. *Practical Assess Res Eval* 2016;21:1–16.
- [282] Henseler J, Ringle CM, Sarstedt M. A new criterion for assessing discriminant validity in variance-based structural equation modeling. *J Acad Market Sci* 2015;43:115–35.
- [283] Legate AE, Hair Jr JF, Chretien JL, Risher JJ. PLS-SEM: prediction-oriented solutions for HRD researchers. *Hum Resour Dev Q* 2023;34:91–109.
- [284] Nitzl C, Roldán JL, Cepeda G. Mediation analysis in partial least squares path modelling. Helping researchers discuss more sophisticated models. *Ind Manag Data Syst* 2016;116:1849–64.
- [285] Carrión GC, Nitzl C, Roldán JL. Mediation analyses in partial least squares structural equation modeling: guidelines and empirical examples. In: Latan H, Noonan R, editors. *Partial least squares path modeling: basic concepts, methodological issues and applications*. Heidelberg: Springer; 2017. p. 173–95.
- [286] Scovell M, Walton A. Identifying informed beliefs about hydrogen technologies across the energy supply chain. *Int J Hydrogen Energy* 2023;48:31825–36.
- [287] Heerma van Voss B, Rafaty R. Sensitive intervention points in China's coal phaseout. *Energy Pol* 2022;163:112797.
- [288] Farmer JD, Hepburn C, Ives MC, Hale T, Wetzter T, Mealy P, et al. Sensitive intervention points in the post-carbon transition. *Science* 2019;364:132–4. 1979.
- [289] Hair Jr JF, Hult GTM, Ringle CM, Sarstedt M, Danks NP, Ray S. A primer on partial least squares structural equation modeling (PLS-SEM). Second. Thousand Oaks, California: SAGE; 2017.
- [290] Becker J-M, Rai A, Rigdon E. Predictive validity and formative measurement in structural equation modeling: embracing practical relevance. *Proceedings of the 34th international conference on information systems*. 2013. p. 1–19.
- [291] Ozili PK. The acceptable R-square in empirical modelling for social science research. *IGI Global* 2023:134–43.
- [292] Benitez J, Henseler J, Castillo A, Schubert F. How to perform and report an impactful analysis using partial least squares: guidelines for confirmatory and explanatory IS research. *Inf Manag* 2020;57:103168.
- [293] Henseler J, Ringle CM, Sinkovics RR. The use of partial least squares path modeling in international marketing. *Adv Int Market* 2009;20:277–319.
- [294] Hasheem MJ, Wang S, Ye N, Farooq MZ, Shahid HM. Factors influencing purchase intention of solar photovoltaic technology: an extended perspective of technology readiness index and theory of planned behaviour. *Cleaner Respo Consum* 2022;7:100079.
- [295] Pan L, Xia Y, Xing L, Song Z, Xu Y. Exploring user acceptance of electric bicycle-sharing systems: an empirical study based on PLS-SEM analysis. *Sensors* 2022;22:7057.
- [296] Bouaguel W, Alsulimani T. Understanding the factors influencing consumers' intention toward shifting to solar energy technology for residential use in Saudi Arabia using the technology acceptance model. *Sustainability* 2022;14:11356.
- [297] Wang S, Esperança JP, Yang W, Zhang JZ. Investigating the determinants of new technology entrepreneurial performance: an empirical study with PLS-SEM and MGA. *J Knowledge Econ* 2023;15:6617–42.
- [298] Park ES, Hwang BY, Ko K, Kim D. Consumer acceptance analysis of the home energy management system. *Sustainability* 2017;9:2351.
- [299] Alam MZ, Kousar S, Rehman ChA. Role of entrepreneurial motivation on entrepreneurial intentions and behaviour: theory of planned behaviour extension on engineering students in Pakistan. *J Global Entreprene Res* 2019;9(1):1–20. 2019;9.
- [300] Wang S, Shi G, Lu M, Lin R, Yang J. Determinants of active online learning in the smart learning environment: an empirical study with PLS-SEM. *Sustainability* 2021;13:9923.
- [301] Hossain MA, Quaddus M, Hossain MM, Gopakumar G. Data-driven innovation development: an empirical analysis of the antecedents using PLS-SEM and fsQCA. *Ann Oper Res* 2024;333:895–937.
- [302] Tehseen S, Sajilan S, Gadar K, Ramayah T. Assessing cultural orientation as a reflective-formative second order construct-a recent PLS-SEM Approach. *Review Integ Bus Econ Res* 2017;6:38.
- [303] Ahmed RR, Streimikiene D, Channar ZA, Soomro RH, Streimikis J. E-banking customer satisfaction and loyalty: evidence from serial mediation through modified E-S-QUAL model and second-order PLS-SEM. *Eng Econ* 2021;32:407–21.
- [304] Lowry PB, Gaskin J. Partial least squares (PLS) structural equation modeling (SEM) for building and testing behavioral causal theory: when to choose it and how to use it. *IEEE Trans Prof Commun* 2014;57:123–46.
- [305] Tian H, Iqbal S, Anwar F, Akhtar S, Khan MAS, Wang W. Network embeddedness and innovation performance: a mediation moderation analysis using PLS-SEM. *Bus Process Manag J* 2021;27:1590–609.
- [306] Sarstedt M, Hair JF, Cheah J-H, Becker J-M, Ringle CM. How to specify, estimate, and validate higher-order constructs in PLS-SEM. *Australas Market J* 2019;27:197–211.
- [307] Sarstedt M, Schloderer MP. Developing a measurement approach for reputation of non-profit organizations. *Int J Nonprofit Voluntary Sect Mark* 2010;3:276–99.
- [308] Avotra AARN, Chenyun Y, Yongmin W, Lijuan Z, Nawaz A. Conceptualizing the state of the art of corporate social responsibility (CSR) in green construction and its nexus to sustainable development. *Front Environ Sci* 2021;9:774822.
- [309] Shmueli G, Ray S, Velasquez Estrada JM, Chatla SB. The elephant in the room: predictive performance of PLS models. *J Bus Res* 2016;69:4552–64.
- [310] Stone M. Cross-validated choice and assessment of statistical predictions. *J Roy Stat Soc B* 1974;36:111–47.
- [311] Geisser S. A predictive approach to the random effect model. *Biometrika* 1974;61:101.
- [312] Sharma PN, Liengard BDD, Hair JF, Sarstedt M, Ringle CM. Predictive model assessment and selection in composite-based modeling using PLS-SEM: extensions and guidelines for using CVPAT. *Eur J Market* 2022;67:1662–77.
- [313] Richter NF, Tudoran AA. Elevating theoretical insight and predictive accuracy in business research: combining PLS-SEM and selected machine learning algorithms. *J Bus Res* 2024;173:114453.
- [314] Kaplan AW. From passive to active about solar electricity: innovation decision process and photovoltaic interest generation. *Technovation* 1999;19:467–81.
- [315] Parkins JR, Rollins C, Anders S, Comeau L. Predicting intention to adopt solar technology in Canada: the role of knowledge, public engagement, and visibility. *Energy Pol* 2018;114:114–22.

- [316] Brückmann G. The effects of policies providing information and trialling on the knowledge about and the intention to adopt new energy technologies. *Energy Pol* 2022;167:113047.
- [317] Singh S, Sahni MM, Kovid RK. What drives FinTech adoption? A multi-method evaluation using an adapted technology acceptance model. *Manag Decis* 2020;58:1675–97.
- [318] Gordon JA, Balta-Ozkan N, Nabavi SA. Exploring the contours of consumer heterogeneity: towards a typology of domestic hydrogen acceptance. *Energy Res Social Sci* 2024;108:103401.
- [319] Furszyfer Del Rio DD, Sovacool BK, Martiskainen M. Controllable, frightening, or fun? Exploring the gendered dynamics of smart home technology preferences in the United Kingdom. *Energy Res Social Sci* 2021;77:102105.
- [320] Bull J. Loads of green washing—can behavioural economics increase willingness-to-pay for efficient washing machines in the UK? *Energy Pol* 2012;50:242–52.
- [321] Kim G, Shin B, Lee HG. Understanding dynamics between initial trust and usage intentions of mobile banking. *Inf Syst J* 2009;19:283–311.
- [322] Park CK, Kim HJ, Kim YS. A study of factors enhancing smart grid consumer engagement. *Energy Pol* 2014;72:211–8.
- [323] Manutworakit P, Choocharukul K. Factors influencing battery electric vehicle adoption in Thailand—expanding the unified theory of acceptance and use of technology's variables. *Sustainability* 2022;14:8482.
- [324] Wolske KS, Stern PC, Dietz T. Explaining interest in adopting residential solar photovoltaic systems in the United States: toward an integration of behavioral theories. *Energy Res Social Sci* 2017;25:134–51.
- [325] Baptista G, Oliveira T. Understanding mobile banking: the unified theory of acceptance and use of technology combined with cultural moderators. *Comput Hum Behav* 2015;50:418–30.
- [326] Alshami M, Abdulghafor R, Aborujilah A. Extending the unified theory of acceptance and use of technology for COVID-19 contact tracing application by Malaysian users. *Sustainability* 2022;14:6811.
- [327] Sabol M, Hair J, Cepeda G, Roldán JL, Chong AYL. PLS-SEM in information systems: seizing the opportunity and marching ahead full speed to adopt methodological updates. *Ind Manag Data Syst* 2023;123:2997–3017.
- [328] Friedl C, Reichl J. Realizing energy infrastructure projects - a qualitative empirical analysis of local practices to address social acceptance. *Energy Pol* 2016;89:184–93.
- [329] Lee MC. Factors influencing the adoption of internet banking: an integration of TAM and TPB with perceived risk and perceived benefit. *Electron Commer Res Appl* 2009;8:130–41.
- [330] Dwivedi YK, Rana NP, Jeyaraj A, Clement M, Williams MD. Re-examining the unified theory of acceptance and use of technology (UTAUT): towards a revised theoretical model. *Inf Syst Front* 2019;21:719–34.
- [331] Bögel P, Oltra C, Sala R, Loes M, Upham P, Dütschke E, et al. The role of attitudes in technology acceptance management: reflections on the case of hydrogen fuel cells in Europe. *J Clean Prod* 2018;188:125–35.
- [332] Van Rijnsoever FJ, Van Mossel A, Broecks KPF. Public acceptance of energy technologies: the effects of labeling, time, and heterogeneity in a discrete choice experiment. *Renew Sustain Energy Rev* 2015;45:817–29.
- [333] Sovacool BK, Griffiths S. The cultural barriers to a low-carbon future: a review of six mobility and energy transitions across 28 countries. *Renew Sustain Energy Rev* 2020;119:109569.
- [334] Sovacool BK, Demski C, Noel L. Beyond climate, culture and comfort in European preferences for low-carbon heat. *Global Environ Change* 2021;66:102220.
- [335] Dimoka A, Banker RD, Benbasat I, Davis FD, Dennis AR, Gefen D, et al. On the use of neurophysiological tools in IS research: developing a research agenda for NeuroIS. *MIS Q* 2012;36:679–702.
- [336] Agarwal S, Dutta T. Neuromarketing and consumer neuroscience: current understanding and the way forward. *Decision* 2015;42:457–62.
- [337] Hair Jr JF, Wolfinbarger Celsi Arthu M, Page MJ. *Essentials of business research methods*. Second. Routledge; 2019.
- [338] Dimoka A, Davis FD. Where does TAM reside in the brain? The neural mechanisms underlying technology adoption. In: *ICIS 2008 Proceedings*; 2008. p. 169.
- [339] Pavlou P, Davis F, Dimoka A. NeuroIS: the potential of cognitive neuroscience for information systems research. *Proceedings of the international conference on information systems*. ICIS; 2007. p. 122.
- [340] Dimoka A, Pavlou PA, Davis FD. NeuroIS: the potential of cognitive neuroscience for information systems research. *Inf Syst Res* 2011;22:687–702.
- [341] Benbasat I, Dimoka A, Pavlou PA, Qiu L. The role of demographic similarity in people's decision to interact with online anthropomorphic recommendation agents: evidence from a functional magnetic resonance imaging (fMRI) study. *Int J Hum Comput Stud* 2020;133:56–70.
- [342] Casado-Aranda LA, Dimoka A, Sánchez-Fernández J. Consumer processing of online trust signals: a neuroimaging study. *J Interact Market* 2019;47:159–80.
- [343] Casado-Aranda LA, Sanchez-Fernandez J. Advances in neuroscience and marketing: analyzing tool possibilities and research opportunities. *Spanish J Market* 2022;26:3–22.
- [344] Casado-Aranda LA, Dimoka A, Sánchez-Fernández J. Looking at the brain: neural effects of “made in” labeling on product value and choice. *J Retailing Consum Serv* 2021;60:102452.
- [345] Venkatraman V, Dimoka A, Pavlou PA, Vo K, Hampton W, Bollinger B, et al. Predicting advertising success beyond traditional measures: new insights from neurophysiological methods and market response modeling. *J Market Res* 2015;52:436–52.
- [346] Doell KC, Berman MG, Bratman GN, Knutson B, Kühn S, Lamm C, et al. Leveraging neuroscience for climate change research. *Nat Clim Change* 2023;13:1288–97.
- [347] Sawe N, Chawla K. Environmental neuroeconomics: how neuroscience can inform our understanding of human responses to climate change. *Curr Opin Behav Sci* 2021;42:147–54.
- [348] Kurtaligi F, Lancelot Miltgen C, Viglia G, Pantin-Sohier G. Using advanced mixed methods approaches: combining PLS-SEM and qualitative studies. *J Bus Res* 2024;172:114464.
- [349] Gordon JA. Towards a unified theory of domestic hydrogen acceptance: a mixed methods multigroup analysis. *Cranfield University*; 2023. <https://dspace.lib.cranfield.ac.uk/items/056da2c7-1f3d-4f32-810a-bd3bb441f56a>.
- [350] Shih Y-Y, Fang K. The use of a decomposed theory of planned behavior to study Internet banking in Taiwan. *Internet Res* 2004;14:213–23.
- [351] Hsu M-H, Chiu C-M. Predicting electronic service continuance with a decomposed theory of planned behaviour. *Behav Inf Technol* 2007;23:359–73.
- [352] Wu JH, Wang SC. What drives mobile commerce?: an empirical evaluation of the revised technology acceptance model. *Inf Manag* 2005;42:719–29.
- [353] Coltman T, Devinney TM, Midgley DF, Venai S. Formative versus reflective measurement models: two applications of formative measurement. *J Bus Res* 2008;61:1250–62.



DSPACE

<https://dspace.org/>

Modelling the innovation-decision process for hydrogen homes: an integrated model of consumer acceptance and adoption intention

Gordon, Joel A.; Balta-Ozkan, Nazmiye; Haq, Anwar Ul; Nabavi, Seyed Ali

2024-12-11

Elsevier

<https://doi.org/10.1016/j.ijhydene.2024.11.061>

Gordon JA, Balta-Ozkan N, Haq AU, Nabavi SA. (2024) Modelling the innovation-decision process for hydrogen homes: an integrated model of consumer acceptance and adoption intention. *International Journal of Hydrogen Energy*, Volume 94, November 2024, pp. 554-579