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Understanding public perceptions of chemical recycling: A comparative study of public attitudes towards coal and waste gasification in Germany and the United Kingdom

Christopher R. Jones [a,*], Roh Pin Lee [b,c], Daphne Kaklamanou [d]

[a] Environmental Psychology Research Group, School of Psychology, University of Surrey, UK
[b] Institute of Energy Process Engineering and Chemical Engineering, TU Bergakademie Freiberg, Germany
[c] Fraunhofer IMWS, Branch Lab 'Circular Carbon Economy', Freiberg, Germany
[d] Department of Psychology, University of Portsmouth, UK

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ABSTRACT

Despite the recognised importance of public acceptance for the success of industrial technologies, little is known about public attitudes towards chemical recycling. We address this gap by investigating the nature of public attitudes towards gasification. Gasification, a form of chemical recycling, can be used to convert carbonaceous wastes into feedstocks that can be used to produce a variety of products (e.g., plastics and transportation fuels) and is seen as a means of supporting the transition towards a circular carbon economy. Using an online questionnaire distributed to diverse samples of the public in Germany ($n = 318$) and the UK ($n = 327$), we assessed participants' attitudes towards gasification after exposure to a short informative video about either coal- or waste-based gasification. These countries were selected as both have advanced chemical recycling industries, but also evidence historic differences in public perceptions of carbon-related technologies. Results show that initial self-reported awareness and knowledge of gasification were very low, although improved by the video. Participants in both countries were generally positive about gasification, particularly waste-based gasification. Mediation analysis indicated that this preference was explained by a stronger positive and weaker negative affective response to the technology, as well as a stronger belief that waste-based gasification is a 'green' technology option that was worthy of investment. Trust in developers was identified as a direct predictor of attitudes towards gasification. The study complements the ongoing techno-economic-ecological evaluations of gasification technologies and has implications for the development of public engagement and communication efforts.

1. Introduction

1.1. Research background

Carbon is essential for the daily functioning of our society; however, its utilisation is associated with significant global challenges (e.g., global warming and natural resource depletion) (Lee and Scheibe, 2020). To combat the adverse impacts associated with carbon utilisation, international efforts have focused predominantly on transitions in the energy and transportation sectors via reduction of primary carbon resource consumption and increased utilisation of renewable energy (Dominković et al., 2018; Zhao et al., 2017). In recent years, however, the challenges of sustainable waste disposal have also highlighted the need to transition towards a more circular economy (Mhatre et al., 2021; Stahel, 2016). It is in this context that interest in chemical recycling technologies has been increasing (Cucciniello and Cespi, 2018; Lee et al., 2021a, 2021b).

1.2. Chemical recycling

Chemical recycling (CR) – also referred to as advanced or feedstock recycling – is a general term used to describe the conversion of carbonaceous waste into chemical 'building blocks' that can be used to create a wide spectrum of products, such as plastics, waxes and transportation fuels (Chen et al., 2021; Cucciniello and Cespi, 2018). CR technologies can contribute to combating the global waste challenge by using waste products as a resource for sustainable production. Moreover, by enabling the use of such waste as an alternative carbon feedstock to crude oil and natural gas for chemical production, CR can also support resource efficiency, resource conservation and emissions reduction in

* Corresponding author at: School of Psychology, University of Surrey, Guildford GU2 7XH, UK.
E-mail address: c.r.jones@surrey.ac.uk (C.R. Jones).

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carbon intensive sectors, such as the chemical and waste management sectors (Lee et al., 2017).

CR technologies are generally categorized as solvolysis, pyrolysis and gasification (Solis and Silveira, 2020). Of these, gasification is an industrial-scale technology suitable for centralized implementation via direct integration in chemical sites (Keller et al., 2020). Gasification works by the thermochemical conversion of carbonaceous materials under high temperature and pressure conditions to release a synthetic gas (i.e. syngas) which can be utilised for the production of a broad range of products (e.g. pharmaceuticals, plastics and transportation fuels) (Dogu et al., 2021; Solis and Silveira, 2020).

Alongside the technological research and development of CR, socio-political discussions about the role of CR within a circular economy have increased, with questions over whether technologies for waste-to-fuels/energy should also be recognised as CR, what CR's role in the waste hierarchy should be, and how significant its potential contribution to a resource efficient and net-zero society might be (Rollinson and Oladejo, 2020; Vahk, 2020). Furthermore, very little is currently known about the social acceptability of CR technologies (although see - Lee, 2019) and yet such considerations could prove crucial to the commercial success of CR.

1.3. Social acceptability and acceptance of emerging technologies

Many studies attest to the key role that the attitudes and actions of social stakeholders can have for the research, development, demonstration and deployment (RDD&D) of industrial-scale technologies (Batel, 2020; Boudet, 2019). Among other things, these studies emphasise the importance of understanding and fostering *public* acceptability and acceptance of such innovation. This is deemed to be particularly important in Western democracies, where publics are often more empowered to influence decision-making relating to the introduction and use of technologies at the socio-political, community and household level (Upham et al., 2015).

While CR might be thought of as a 'benign' technology option that will not be of interest to publics, one should not assume that there will be no objections to its use. Past studies have identified evidence of public concern over other forms of waste management (e.g., incineration, landfill), and have advocated the need for dialogue in order to address public concerns, improve public understanding and acceptance of facilities, promote engagement in waste-management programmes (e.g., recycling) and encourage the purchase and use of products derived from waste streams (e.g., Garnett et al., 2017; Liu et al., 2021, 2018). Despite the importance of public opinion to the 'real world' success of waste-management technologies, however, to our knowledge there has been no targeted research into public attitudes of large-scale gasification technologies for the purposes of CR.

While concepts such as the circular economy and recycling tend to be viewed favourably by publics (Cherry et al., 2018; Sijtsema et al., 2019), it is presently unclear how publics will receive and respond to discussions about gasification. It is important that this gap in our knowledge is addressed, as the way in which gasification (and CR more widely) becomes socially represented will have important consequences for public attitudes and actions (Batel and Devine-Wright, 2015). For example, should citizens view gasification technologies as comparable to incineration – harbouring comparable technological or environmental risks – then one might anticipate less favourable attitudes and lower acceptance of the technology, than if gasification is deemed as being akin to recycling and thus complementary to notions of sustainability (Baxter et al., 2016; Liu et al., 2021).

While not focused on public opinion per se, Levidow and Upham (2016) provide some initial insight into the social representations of gasification among other key stakeholder groups (e.g. technology developers, potential buyers and users, and governmental bodies). Using a mix of document analysis, interviews, and surveys, they found that gasification among these stakeholder groups was only weakly differentiated from incineration, with extant opinions about incineration (be they good or bad) strongly influencing perceptions. For instance, among those who were favourable to incineration as a form of waste management, gasification was viewed positively: a technology embodying the positive features of incineration, while avoiding the drawbacks.

Comparable research from the publics' perspective is currently absent, however, there is reason to believe that people might be cautious about gasification. This is not only due to its novelty but also due to its links to heavy industry and the production of carbon-based products. Indeed, similar concerns have been registered in relation to analogous industrial technologies, notably Carbon Dioxide Utilisation, where publics are seen to question its pro-environmental credentials (Jones et al., 2017b, 2017a).

1.4. Research objective and research questions

In sum, while there is growing awareness of the importance of considering and integrating public opinion into decisions regarding the RDD&D of emerging industrial technologies, studies are yet to provide an in-depth appraisal of public attitudes towards CR technologies like gasification. The present study addresses this gap by exploring the nature and antecedents of public attitudes towards two forms of gasification technology (coal and municipal waste) in Germany and the UK. The rationale for selecting these two countries is provided below (see Section 2.1, Research context). This study is timely given the advancing interest and investment in CR technologies, and the role that insight into public attitudes could play in informing socio-political debates and decision-making processes regarding the future use of CR. This study complements the ongoing techno-economic and ecological evaluations of gasification as an industrial-scale CR option (Keller et al., 2020; Lee et al., 2021a, 2021b).

In the current study, an online questionnaire-based survey (QBS) incorporating an informative video (henceforth, 'infomercial') about gasification was delivered to representative population samples of the German and UK public. This exploratory study was designed to assess the nature of public attitudes towards gasification in each country and to investigate any divergence in these attitudes due to national context or gasification feedstock type (coal vs. waste). The following three research questions were formulated to guide the investigation:

(1) What is the nature of people's general attitudes towards gasification technology and are there differences in these attitudes in Germany and the UK?
(2) Are there differences in general attitudes towards gasification technology following the receipt of information identifying waste vs. coal as the primary feedstock?
(3) To what extent are any differences in attitudes towards the use of different feedstocks explained by divergence in some of the key antecedents of attitude (i.e., perceived risks and benefits, positive and negative affect, and trust in developers)?

2. Methods

2.1. Research context

The current study investigates public attitudes towards gasification (particularly for the purposes of CR) in Germany and the UK. These countries represent the two largest, industrialised, democratic economies in Europe in terms of gross domestic product (Clark, 2021) and provide a good comparative context for exploring public attitudes for a number of reasons.

Firstly, waste incineration is a central pillar of waste management in both countries (Jaron and Kossmann, 2018; Sönnichsen, 2020; Tiseo, 2021). By offering the opportunity to recirculate waste back into production cycle, CR technologies (like gasification) hold the potential to

help reduce the carbon footprint of the waste management sector and generate higher value from waste. With this in mind, CR is eliciting growing interest in both countries (Lee et al., 2021a, 2021b; Partridge and Medda, 2019).

Secondly, both countries have advanced chemical industries. In recent years, the chemical industry in both countries has intensified efforts to integrate carbonaceous waste products – especially plastics and packaging waste – into their production cycle via CR (Pullin and Marsh, 2018; Verband der Chemischen Industrie (VCI), 2020). A rationale for this is to reduce 'risky' import dependency. With a reduction in oil production in the North Sea, the UK is becoming increasingly reliant on fossil imports for its chemical production (House of Commons Exiting the European Union Committee, 2017) and the German chemical industry is similarly dependent on fossil imports (Lee and Scheibe, 2020).

Thirdly, in the context of assessing comparative public attitudes, there is good reason to focus on Germany and the UK. Specifically, in the context of other emerging carbon-management technology options, Germans have been hypothesised and/or found to be less favourable than those within the UK (Shackley et al., 2007; Upham and Roberts, 2011). For example, in a survey about Carbon Capture and Storage (CCS) conducted on 512 stakeholders from across the EU (including UK), respondents from the UK indicated that there would be little public opposition to the introduction of CCS (around 10%) compared with public opposition estimates of around 35% in Germany (Shackley et al., 2007). Also, in the context of Carbon Dioxide Utilisation (CDU), while broadly similar in their valence, studies have revealed there to be qualitative differences in the beliefs underpinning German and UK attitudes towards the technology (Jones et al., 2017a). With this in mind, one might anticipate there to be differences between Germany and the UK with regards public attitudes, which could hold implications for public engagement and communications in each country. This is likely to be particularly true in the case of gasification technologies, as the term 'gasification' in German ('vergasung') is reminiscent of the terminology associated with the use of gas chambers in the concentration camps of World War II.

2.2. Participants and design

An experimental questionnaire-based survey (QBS) utilising a 2 (Nationality: Germany vs. UK) × 2 (Gasification Infomercial: coal vs. municipal waste) between-subjects design was distributed to representative samples (with respect to age and gender) of the German and UK public via an online participant panel provider (Qualtrics). We did not target those involved in the CR sector directly but were instead keen on accessing a general sample of the lay public from each country. The QBS took place across four weeks in February–March 2019 (UK) and May–June 2020 (Germany). Participants were required to be 18+ years and to identify as nationals of the target country. Completers received a small monetary payment (approx. £2 GBP/€2.35 EUR) administered by Qualtrics. All participants provided informed consent before participating in the survey. The study protocol was subject to appropriate ethical review at the University of Surrey, UK. The datasets generated during the current study are available from the corresponding author upon reasonable request.

A total of $N = 687$ participants completed the survey.[1] Having removed participants ($n = 42$) that did not identify as a UK or German nationals, a final viable sample of $n = 327$ UK and $n = 318$ German participants was obtained. This sample size is similar to those recruited in cross-national comparisons of public attitudes towards other emerging technologies (e.g., GM Food, Bredahl, 2001; nuclear fusion, Jones et al., 2019). Details of the key demographics of these participants are provided in Table 1 and confirm success in recruiting a diverse sample in each country. The modal participant in both countries was 35–64 years old, with secondary school level education.

2.3. Survey details

This section provides abridged details of the QBS, outlining the questions of direct relevance to the current study. Full details of the UK and German versions of the QBS can be found in the Supplementary Information (SI). The German version of the survey was derived from the UK version but contained fewer questions. The current study only analyses items where there was direct comparability between the UK and German surveys. The QBS took approx. 19 min (UK) or 16.5 min (Germany) to complete.

2.3.1. Key demographics

Participants started by registering their age, gender, nationality, education level (see Table 1). Age category groupings were defined by Qualtrics to aid with quota-sampling. Gender, age, and education response options were categorical. Nationality was also categorical although in the UK this was an open response that was latterly recoded as UK national vs. other nationality (dichotomous).

2.3.2. Initial awareness and knowledge of gasification

Participants were asked if they had previously heard anything about gasification technologies (Yes, No, Don't know). Subjective knowledge was assessed by asking participants how much they thought they currently knew about the technology (6-point scale: 1 = Nothing, I have never heard of it; 6 = A great deal). Objective knowledge was assessed by asking people to pick which one of four statements (presented in a randomised order) best described 'gasification technology'. Only one of these statements accurately described gasification (see SI for these statements).

2.3.3. Infomercial about gasification technologies

Participants were randomly assigned to either the 'coal' or 'waste' gasification condition where they viewed a short (approx. 3 min) cartoon-based infomercial about the technology. The informercial utilised for the study is available at: https://tu-freiberg.de/en/steep-carbontrans/mediadownload/gasification. The informercial is adapted to show only coal as feedstock in the 'coal gasification' condition, and waste as feedstock in the 'waste gasification' condition. A summary outline of the video script is provided below. German and English language versions of the film were produced for Germany and the UK, respectively. Participants were advised to have their computer audio on while watching the video, however, all spoken narration also appeared as text on screen. Still-shots from the film can be seen in Fig. 1.

The infomercial was narrated by CARBI (a cartoon carbon atom), voiced by the second author. CARBI first invited viewers to consider that many things we use (e.g., clothing, plastics) are chemical products made from carbon. Next, CARBI informed viewers that oil and natural gas are traditionally used as sources of carbon for these products, before announcing that the need to conserve oil and gas, and reduce import dependency for these resources, is driving the hunt for alternative carbon sources for making chemical products. At this point the video diverged for the Coal and Waste groups.

- Coal Gasification: CARBI outlined that one source that is being considered is coal, which is a fossil resource like oil and gas, but is more abundant and thus will be available for a longer time. It was noted that coal is currently combusted to generate electricity.
- Waste Gasification: CARBI outlined that household waste such as plastic bottles and packaging represent a valuable source of carbon. It was noted that such waste is currently combusted to produce electricity or buried in landfill.

[1] The full survey comprised 6 conditions designed to investigate the impact of the (in-)civility of social commentary on perceptions of gasification associated with the presentation of the coal or waste infomercial ($N = 2700$). The present analyses focus solely on the data from the two control conditions (i.e., where no social commentary was present).

Table 1
Key demographics of the Germany and UK samples.

		Nationality		
		Germany	UK	Total
		$n = 318$	$n = 327$	$N = 645$
Age (years)	18–24	29 (9.1%)	37 (11.3%)	66 (10.2%)
	25–34	49 (15.4%)	67 (20.5%)	116 (18.0%)
	35–64	154 (48.4%)	171 (52.3%)	325 (50.4%)
	65+	86 (27.0%)	52 (15.9%)	138 (21.4%)
Gender	Male	154 (48.4%)	165 (50.5%)	319 (49.5%)
	Female	162 (50.9%)	162 (49.5%)	324 (50.2%)
	Other/no response	2 (0.6%)	0 (0%)	2 (0.4%)
Highest completed education	No formal/primary	3 (0.9%)	1 (0.3%)	4 (0.6%)
	Secondary	156 (49.1%)	116 (35.5%)	272 (42.2%)
	College	52 (16.4%)	84 (25.7%)	136 (21.1%)
	Uni (undergraduate)	32 (10.1%)	82 (25.1%)	114 (17.7%)
	Uni (graduate)	0 (0%)	39 (11.9%)	39 (6.0%)
	Other[a]	75 (23.6%)	5 (1.5%)	80 (12.4%)

[a] Respondents stating 'other' forms of education listed vocational qualifications, apprenticeships, and other forms of occupational training.

The videos then converged with viewers informed that special technologies are required to convert these alternative sources into carbon sources for the manufacture of chemical products. Gasification was introduced as one such technology. A brief description of gasification was then provided before the advantages of gasification were then contrasted with several disadvantages: (a) that CO_2 would still be produced as a by-product of gasification; (b) that chemical products derived from gasification would be more costly than that derived from traditional sources; and (c) that the sector would require the employment of skilled people.

The infomercial ended with CARBI asking viewers to consider their own opinions about whether gasification technology could be the key to enabling the use of alternative carbon sources to produce many of the things we use daily. Participants then received an attention check question asking them to recall the theme of the video (Coal gasification, Waste gasification, Neither of the above). Those who answered incorrectly at this stage were ejected from the survey.

2.3.4. Video evaluation

Subjective knowledge was then re-assessed by asking participants how much they thought they *now* knew about the technology (6-point scale: 1 = Nothing, I have never heard of it; 6 = A great deal), before they were invited to evaluate the video information on 6 qualitative dimensions (5-point scale: 1 = strongly disagree; 5 = strongly agree + don't know): "*For me the information provided was: understandable; balanced and unbiased; of good quality; sufficient for me to*

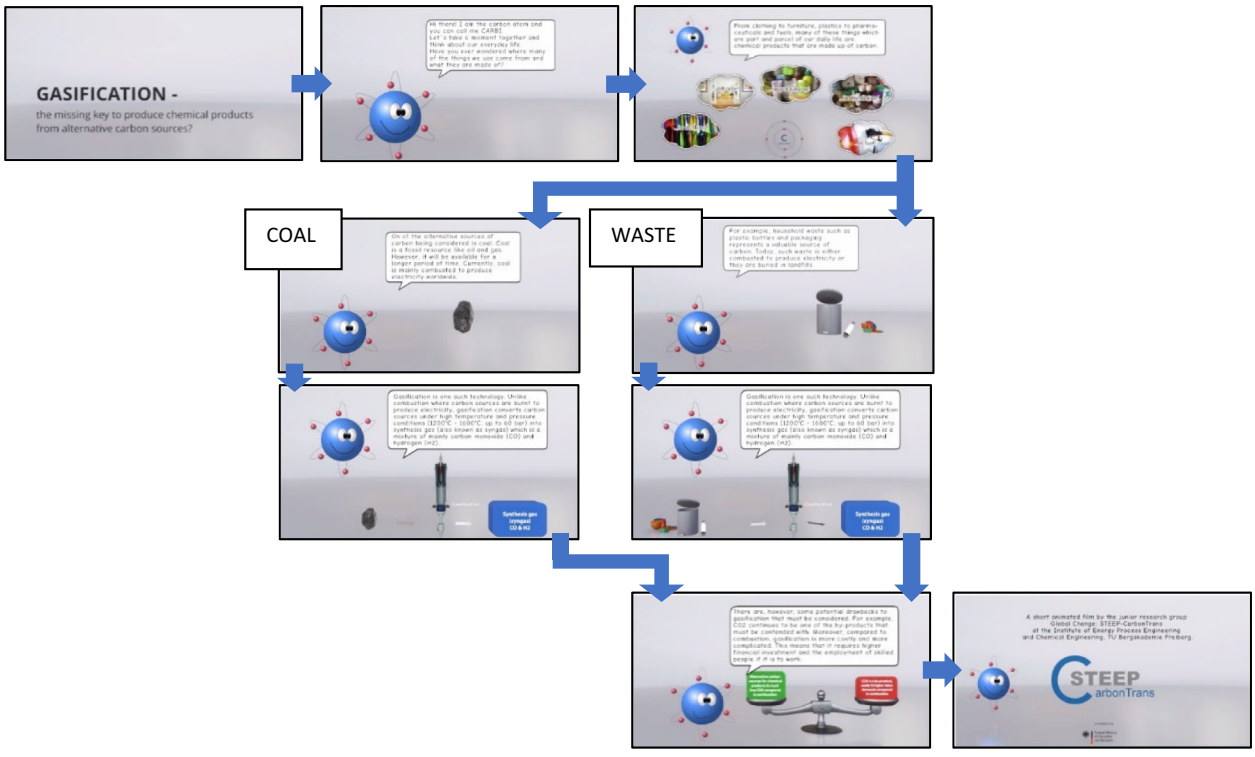

Fig. 1. Stills from the coal and waste gasification infomercials.
Participants start by being told that carbon forms the basis of many of the things that we use from day-to-day, before being randomised to the coal or waste gasification condition. The infomercials then reconverge to provide basic details of gasification and some of the benefits and drawbacks of gasification. The infomercials are credited to the STEEP-CarbonTrans project which is funded by the German Federal Ministry of Education and Research (BMBF).

make informed decisions; trustworthy; makes me want to learn more about gasification".

2.3.5. Assessment of informed attitudes towards gasification technologies

Participants answered a series of questions (created by the current authors) designed to assess attitudes to gasification and a core set of attitude antecedents (i.e., perceived risks and benefits; positive and negative affect; and trust in developers). The following items all use 5-point response scales (1 = Strongly disagree; 5 = Strongly agree + don't know). While completing this section, participants were also required to complete an attention check item. Those who answered incorrectly to this item were ejected from the survey.

i. **Attitude towards gasification**

Assessed using a composite 3-item measure (UK: $\alpha = 0.86$; Germany: $\alpha = 0.85$): (1) "*I would support the development and use of gasification in my country*"; (2) "*I would be comfortable buying products made using carbon sourced from gasification technologies*"; (3) "*All things considered, I think that gasification technologies are a good thing*". Participants also completed a single-item measure of attitude certainty: "*I am sure of my opinions of gasification technologies*".

ii. **Antecedents of attitude**

Assessed using 6-items relating to perceived risks and benefits, and positive and negative affect. Items were treated individually in the analysis and are not combined into composite measures. Two items assessed technological and environmental risk (e.g., "*Gasification technologies are technologically risky*"). Two items assessed financial and environmental benefits (e.g., "*Gasification is a green technology option*"). One item assessed positive affect (i.e., "*Emotionally, I just get a good feeling/I generally feel uneasy about gasification*"). One item assessed negative affect (i.e., "*Emotionally, I generally feel uneasy about the use of gasification technologies*"). The term 'emotionally' was used in the affect-oriented questions in an attempt to tap participants' feelings about the technology, as opposed to a more general cognitive appraisal of the technology.

Trust in developers was assessed using a 5-item scale that was collapsed into a composite measure (UK: $\alpha = 0.83$; Germany: $\alpha = 0.86$) (e.g., "*I trust that the people developing gasification technologies know what they are doing*" and "*I trust that the people developing gasification have the interests of the public at heart.*")

3. Results

This section covers four key analyses: (1) baseline (pre-infomercial) levels of awareness and subjective knowledge of gasification; (2) - participant evaluations of the coal and waste gasification infomercials and their relative impact on self-claimed knowledge; (3) participants' general attitudes towards gasification following exposure to the infomercials; (4) mediation analysis of the potential factors accounting for differences in participants' preferences for waste over coal gasification.

Parametric statistical analysis was used where the relevant assumptions associated with the tests were met. Where this was not the case, appropriate non-parametric alternatives were used. For further insight into the nature, rationale and purpose of the statistical analyses used in this study, please see Field (2018) or George and Mallerey (2019).

3.1. Pre-infomercial awareness and knowledge of gasification

Pre-infomercial levels of awareness and knowledge of gasification were evaluated (see Table 2 for frequency data). Overall, three quarters of participants (74.9%) claimed not to have heard of gasification at the start of the survey, confirming its status as an unfamiliar technology. There was a significant difference between the countries with respect to initial self-claimed awareness ($p < .001$), with relatively higher levels in Germany (21.4%) versus the UK (10.1%). Also, a greater number of German participants (14.8%) responded 'don't know' versus the British participants (4.3%).

Table 2
Pre-infomercial awareness and knowledge of gasification in Germany and the UK.

		Nationality	
		Germany ($n = 318$)	UK ($n = 327$)
Self-claimed awareness	Yes	68 (21.4%)	33 (10.1%)
	No	203 (63.8%)	280 (85.6%)
	Don't know	47 (14.8%)	14 (4.3%)
	χ^2 (2)	42.14***	
Subjective knowledge	A great deal	3 (0.9%)	0 (0.0%)
	A lot	8 (2.5%)	1 (0.3%)
	Moderate	22 (6.9%)	13 (4.0%)
	Little	44 (13.8%)	36 (11.0%)
	Nothing (only name)	90 (28.3%)	72 (22.0%)
	Nothing	151 (47.5%)	205 (63.7%)
	χ^2 (5)	21.63**	
Objective knowledge	Total accurate - create syngas	103 (32.4%)	179 (54.7%)
	Total inaccurate	215 (67.6%)	363 (56.3%)
	- Incinerate waste	106 (33.3%)	58 (17.7%)
	- Produce carbon fibre	30 (9.4%)	32 (9.8%)
	- None of the above	79 (24.8%)	58 (17.7%)
	χ^2 (2)	32.73***	

Notes. p-value significance = *<.05; **<.01; ***<.001.

There were differences between the countries in terms of self-report knowledge of gasification ($p = .001$). British participants were more likely to claim that they 'knew nothing at all' (63.7%) versus the German participants (47.5%). By contrast, there was a tendency towards Germans claiming to have heard of the term 'gasification' (28.3%) versus the British (22.0%). However, despite German participants claiming greater knowledge of gasification, they were significantly worse at selecting the objectively correct description of gasification ($p < .001$). Over half the British participants (54.7%) accurately identified gasification correctly versus a third of the German participants (32.4%). A comparable proportion of the German participants wrongly believed that gasification referred to a form of incineration designed to produce electricity and heat (33.3%).

3.2. Evaluation of infomercial and its impact on self-claimed knowledge of gasification

Differences in the perceived quality of the coal and waste infomercials (using the composite quality evaluation scores) were assessed together with an evaluation of national differences. As the assumption of homogeneity of population variances was violated for infomercial evaluation (Levene's test: $p = .003$), non-parametric tests were used. The sample was split into four groups to delineate the nationality and infomercial combinations:

- *Group GC* (Germany + Coal infomercial)
- *Group GW* (Germany + Waste infomercial)
- *Group UC* (UK + Coal infomercial)
- *Group UW* (UK + Waste infomercial)

Participants in both countries evaluated the infomercials positively (*Medians* > 3.0); however, a Kruskal-Wallis test revealed that there was a significant difference between groups in the evaluations of the infomercials ($p = .003$). Mann-Whitney U tests

Table 3
Group differences in evaluations of infomercial quality.

Nationality	Infomercial	Group	Median	Mean rank	Mann-Whitney U tests
Germany	Coal ($n = 150$)	GC	3.83	315.05	*n.s.*
	Waste ($n = 168$)	GW	4.00	362.55	U (vs. GC) = 10822*
					U (vs. UC) = 10467***
					U (vs. UW) = 11800*
UK	Coal ($n = 163$)	UC	3.67	287.60	*n.s.*
	Waste ($n = 163$)	UW	3.83	320.96	*n.s.*
Kruskal-Wallis H (3)			13.87*		

Notes. n.s. = not significant; *p*-value significance = *<.05; **<.01; ***<.001.

confirmed that participants in *Group GW* evaluated the infomercial most favourably. The median rating in *Group GW* was significantly higher than in *Group GC* ($p = .037$), *Group UC* ($p < .001$), and *Group UW* ($p = .029$). All other comparisons were not statistically significant ($ps \geq .078$) (see Table 3). Because of the identified differences, perceived Infomercial quality was controlled for in the subsequent analysis.

The effect of the infomercials on participants' self-reported knowledge about gasification was analysed, alongside whether the magnitude of any change differed between the countries and/or with respect to the type of infomercial shown. To contend with the positive skew towards low levels of subjective knowledge of gasification, a pre- and post-infomercial difference score was created for each participant (see Table 4).

A 2 (Nationality: Germany vs. UK) × 2 (Infomercial: Coal vs. Waste) between-subjects ANOVA examined the relative size of the difference scores among the sample. There was a significant main effect of *nationality*, with German participants reporting a larger increase in their subjective knowledge versus the British participants, $F(1, 641) = 6.00$, $p = .015$, $\eta^2 = 0.009$. There was no main effect of *infomercial* ($p = .112$), and no significant *nationality* ∗ *infomercial* interaction ($p = .359$). Thus, while participants in all conditions tended to show an improvement in their self-claimed knowledge, German participants showed a larger improvement compared to the British participants. The relative impact of the different infomercials on self-reported knowledge was statistically comparable.

3.3. General attitudes towards gasification

Differences in general attitudes towards gasification following the different infomercials and the impact of nationality were examined (see Fig. 2) using a 2 (Nationality: German vs. UK) × 2 (Infomercial: waste vs. coal) between-subjects ANCOVA (controlling for infomercial quality). On average, participants were positive about gasification in each condition, although there was a main effect of *infomercial*. Those viewing the waste infomercial held more positive attitudes than those viewing the coal infomercial, $F(1,626) = 22.88$, $p < .001$, $\eta^2 = 0.035$. The main effect of *nationality* ($p = .599$) and the *nationality* ∗ *infomercial* interaction ($p = .237$) were not statistically significant.

Table 4
Changes to subjective knowledge of gasification pre- and post-infomercial.

Nationality	Infomercial	Group	Mean subjective knowledge (SD)		
			Pre-info.	Post-info.	Difference
Germany	Coal ($n = 150$)	GC	1.97 (1.20)	3.62 (0.97)	+1.65 (1.16)
	Waste ($n = 168$)	GW	1.87 (1.05)	3.74 (0.88)	+1.90 (1.13)
UK	Coal ($n = 163$)	UC	1.58 (0.85)	3.10 (0.87)	+1.52 (1.03)
	Waste ($n = 164$)	UW	1.56 (0.88)	3.14 (0.91)	+1.58 (1.04)

Notes. Pre-info./post-info. = pre-infomercial/post-infomercial. SD = standard deviation.

3.4. Explaining the difference in attitudes following exposure to the coal and waste infomercials

To understand whether the difference in participants' attitudes towards gasification following exposure to the infomercials was mediated by the seven identified antecedents of attitudes, a parallel mediation analysis using PROCESS Version 3.5 for SPSS (Model 4 with 10,000 bootstrapped samples and 95% CI) was carried out (Hayes, 2018). The outcome variable was general attitude towards gasification (*attitude*). The predictor variable was the infomercial viewed (*condition*). The mediator variables were: (1) perceived technological risk; (2) perceived environmental risk; (3) belief that gasification is a worthwhile financial investment; (4) belief that gasification is a green technology option; (5) positive affect; (6) negative affect; and (7) trust in developers (see Table 5). Due to the differences identified in the preceding analyses, infomercial quality and nationality were included as covariates in the analysis.

As can be seen in Fig. 3 the total effect (c) of condition on attitude was significant, confirming that there was a difference in attitudes towards gasification following exposure to each infomercial. The model was statistically significant, accounting for 35% of the variance in attitude, $R^2 = 0.35$, $F(3, 529) = 93.37$, $p < .001$. In the mediation model, the direct effect (c′) of condition on attitudes was not significant, indicating that the difference in attitude between the conditions was fully mediated by the additional variables. The overall model was statistically significant, accounting for 86% of the variance in attitude, $R^2 = 0.86$, $F(10, 522) = 151.42$, $p < .001$. For full details of the direct effects and indirect effects of the mediation model, see Table A1, Appendix A.

Reference to the mediation model (see Fig. 3) indicated that the difference in attitudes between the conditions was because participants in the waste condition were: (a) more emotionally positive and less emotionally negative about gasification; and (b) more likely to perceive gasification as a green technology option and worthy of financial investment. Reference to the partially standardized indirect effects confirmed that the largest significant mediated effect within the model related to positive affect ($b = 0.037$, SE = 0.01, LLCI = 0.02, ULCI = 0.06). The indirect effects of negative affect ($b = 0.020$, SE = 0.01, LLCI = 0.01, ULCI = 0.03), perceptions that gasification was worthy of investment ($b = 0.023$, SE = 0.01, LLCI = 0.01, ULCI = 0.04) and a green technology option ($b = 0.019$, SE = 0.01, LLCI = 0.01, ULCI = 0.03) were roughly comparable in size with one-another, although notably smaller than for positive affect.

Technological and environmental risk were not significant mediators of the between condition difference in attitudes towards gasification and were not direct predictors of attitude within the model. Waste gasification was, however, seen as being less environmentally risky than coal gasification. Trust in developers was fairly high in both countries, but trust did not help to explain the differences in attitudes towards gasification in each condition. Trust was, though, a direct predictor of participants' attitudes towards gasification (i.e., the more trusting people were of the developers the more positive they were towards coal and waste gasification).

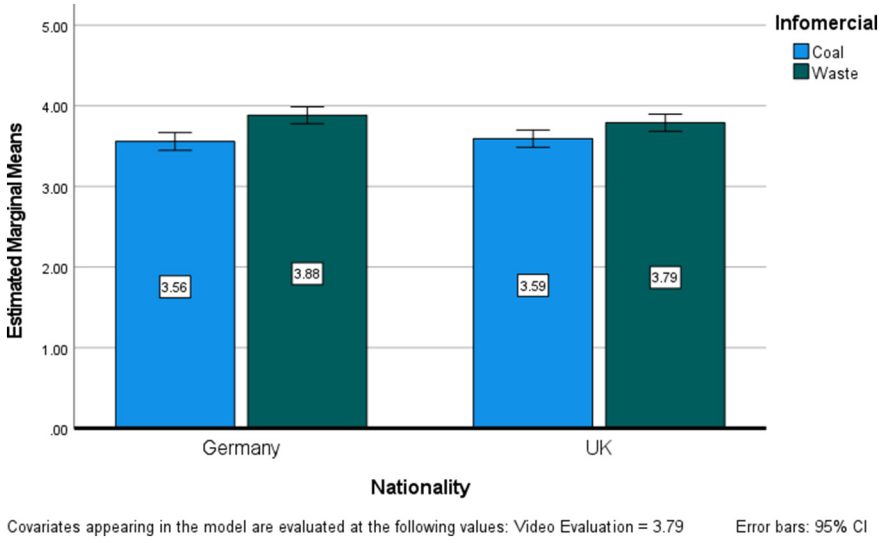

Fig. 2. Mean general attitudes towards gasification following exposure to the coal and waste infomercials in Germany and the UK.

4. Discussion

This exploratory study provided first insights into the nature of public attitudes towards gasification and investigated divergences in these attitudes due to national context (Germany vs. UK) and gasification feedstock type (coal vs. waste). This discussion will consider the key findings relating to each of stated research questions, before addressing the limitations and future directions for work in this area. It will end by considering the implications for policy and industry decision-makers, particularly in terms of public engagement and communication efforts relating to gasification.

4.1. Key findings

The results indicate that current public awareness of gasification in both the UK and Germany is low. At the beginning of the study, less than a quarter of our participants claimed to have heard of gasification. Self-assessed (subjective) knowledge was also low in both countries. German participants claimed to have more knowledge than the British; however, they were objectively less accurate at defining gasification, tending to more frequently confuse it with incineration. The initially low levels of awareness and self-claimed knowledge justify our research approach. Prior research on emerging technologies has utilised the provision of information to reduce the prospect of measuring pseudo-attitudes (i.e. weak and potentially erroneous evaluations of an attitude object that are highly changeable in response to new information) (de Best-Waldhober et al., 2009). This study utilised video-based 'infomercials' to inform participants about gasification before attitudes were assessed. Participants in both nations indicated the infomercials were of good quality and that exposure to them had increased their knowledge of gasification. This increases confidence that the attitudes towards gasification recorded in the survey arose from a relatively informed position.

The impact of the infomercial was more pronounced among the German sub-sample, which is likely due to it successfully correcting the misperception that gasification was a form of incineration among the Germans. Countering misperceptions about the nature and purpose of gasification will be crucial for future public engagement and communication efforts, particularly given the impact that social representations of emerging technology can have for public attitudes and acceptance of such technology (Batel and Devine-Wright, 2015).

Overall, informed general attitudes towards gasification in both countries were comparable and mildly positive. While this finding is perhaps surprising given the historical differences in how UK and German publics have been found to view other carbon-related technology options (Jones et al., 2017a; Shackley et al., 2007; Upham and Roberts, 2011), it is likely that the framing used within the infomercials contributed to the emergence of such positive attitudes in both country contexts. The focus of the infomercials was on the lower carbon footprint of gasification relative to combustion, as well as the consistency of gasification with a more circular economy. Studies into other emerging industrial technologies (e.g. smart grids, Carbon Dioxide Capture and Utilisation) have observed positive impacts of such pro-environmental framing on public opinion (Jones et al., 2017a; Peters et al., 2018; Whitmarsh et al., 2019), which makes sense given the prominence of

Table 5
Mean evaluations of the antecedents of general attitudes in Germany and the UK.

Nationality	Mean (SD)						
	Tech_Risk	Env_Risk	Worth_Invest	Green_option	Pos_Affect	Neg_Affect	Trust
Germany	2.67 (0.96)	3.17	3.73	3.39	3.67	2.67	3.56
$n = 265$		(1.05)	(1.03)	(1.12)	(1.04)	(1.13)	(0.86)
UK	3.01	2.98	3.63	3.26	3.36	2.66	3.50
$n = 268$	(0.89)	(0.91)	(0.87)	(1.00)	(0.91)	(0.95)	(0.76)
Total	2.84	3.08	3.68	3.33	3.51	2.66	3.53
$N = 533$[a]	(0.94)	(0.99)	(0.95)	(1.06)	(0.99)	(1.04)	(0.81)

Notes. 5-point scale: (1) strongly disagree to (5) strongly agree. SD = standard deviation. Technological risk (*Tech_Risk*); Environmental risk (*Env_Risk*); Worthwhile investment (*Worth_Invest*); Green technology option (*Green_Option*); Positive affect (*Pos_Affect*); Negative affect (*Neg_Affect*); Trust in developers (*Trust*).
[a] The size of the total sample and sub-samples are reduced due to listwise deletion of participants.

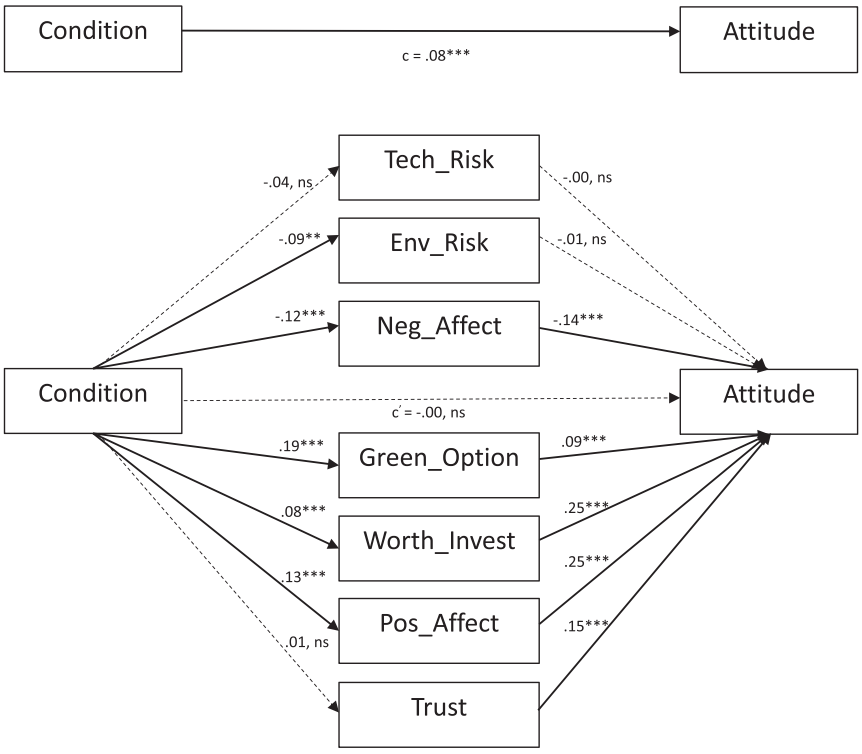

Fig. 3. Mediation model explaining the difference in attitudes towards gasification following exposure to coal versus waste infomercial.
The upper model shows the total effect of infomercial condition on attitude, $R^2 = 0.35$, $F(3, 529) = 93.37$, $p < .001$. The lower mediation model shows that the relative preference for gasification following exposure to the waste infomercial was explained by greater positive affect, lower negative affect, and a stronger belief that gasification was a green technology option and worthy of financial investment, $R^2 = 0.86$, $F(10, 522) = 151.42$, $p < .001$. Model controls for nationality and infomercial evaluation. Condition = Coal infomercial (0) Waste infomercial (1). Technological risk (*Tech_Risk*); Environmental risk (*Env_Risk*); Worthwhile investment (*Worth_Invest*); Green technology option (*Green_Option*); Positive affect (*Pos_Affect*); Negative affect (*Neg_Affect*); Trust in developers (*Trust*). Dashed lines depict non-significant pathways. Complete lines depict significant pathways: $^{***}p < .001$, $^{**}p < .01$, $^{*}p < .05$.

public concern for the environment. This framing can also account for the differences in attitudes towards 'waste' and 'coal' gasification. As waste gasification is perceptively more congruent with notions of recycling and reduced reliance on (finite) fossil fuels than coal gasification, it is perhaps to be expected that participants would be more preferable to this option. The mediation analysis provided support for this conclusion, by showing that participants saw waste gasification as a 'greener' technology option.

The prominence of positive and negative affect as predictors of attitudes towards gasification is noteworthy given that affect has been found to be important when people are forming judgments about new and unfamiliar things. The risk-as-feelings hypothesis (Loewenstein et al., 2001) and affect heuristic (Slovic et al., 2007) both highlight how people make judgments about attitude objects on the basis of their 'gut' reactions to them, including in relation to emerging and established technologies (e.g. Siegrist and Sütterlin, 2016). It is possible that the perceived congruency of gasification with notions of sustainability led to the positive affective response among participants and to generally favourable opinions of the technology, particularly in the case of waste gasification. Also of note is the role that trust played in predicting participants attitudes towards gasification. While not mediating the differences in preferences for the two forms of gasification, trust was identified as a direct positive predictor of attitudes (see Fig. 3). Due to the low level of self-claimed knowledge of gasification, the emergence of trust as a heuristic for guiding attitudes is to be expected (Siegrist, 2021). Trust in developers has been found to be an important determinant of attitudes and acceptance of myriad controversial and/or emerging technologies, particularly where people hold limited knowledge (Siegrist, 2021; Siegrist and Cvetkovich, 2000). As trust was high in our study, this likely contributed to the positive attitudes towards gasification observed in both countries.

4.2. Limitations and future directions

4.2.1. Items, measures, and constructs

The survey items used to assess several constructs were bespoke and were single-item measures (e.g., our measures of positive and negative affect). While it is commonplace to use single-item measures, even for complex constructs (Postmes et al., 2013; Robins et al., 2001) they can be vulnerable to error (e.g. if a participant mis-reads or misunderstands the item). Future research might benefit from identifying or developing multi-item measures for the constructs of interest.[2] Similarly, our measure of trust was also brief (5-items) and married together items relating to social trust (perceived integrity), confidence (perceived competency) and procedural and distributive fairness. While this measure had excellent internal consistency, future research should seek to differentiate and model the relative importance of these individual constituents.

Second, we used a general measure of attitudes towards gasification as the primary dependent variable. Bearing in mind that differences were found in preferences for coal vs. waste gasification following exposure to the infomercials, future studies might benefit from having more purposefully designed scales to specifically assess the nature and antecedents of public preferences for different feedstock options. Additionally, research might also investigate attitudes towards gasification in the context of other technology options. Evidence shows that comparative scenarios (i.e. where target technologies are considered relevant alternatives alongside alternatives), can lead to differences in reported preferences versus contexts where technologies are considered in isolation (Demski et al., 2017; Jones et al., 2012).

[2] In the UK version of the survey, multi-item measures for the key antecedents of attitude were utilised; however, these measures were consolidated in the German survey on the grounds of survey duration and related distribution costs.

Third, the study's focus on assessing attitudes as opposed to acceptance (or support) for gasification, should be recognised. There is a qualitative distinction between acceptability (attitude) and acceptance (behaviour) and technology acceptance is predicted by more than just a person's attitudes (e.g. perceived social norms) (Huijts et al., 2012). Thus, we cannot assume that the positivity registered towards gasification in this study will reflect active support for these technologies. That said, the obtained results should provide a fair representation of how publics in Germany and the UK are likely to react to early discussions of gasification at the socio-political level (Upham et al., 2015).

4.2.2. Frame of communication

As outlined above, participants may have responded positively to the pro-environmental framing of gasification within the infomercials. There are several questions stemming from this, for instance, whether the preferences observed would persist in a context where the environmental sustainability benefits were de-emphasised and/or where the emphasis was placed on a different characteristic of the technology (e.g., the economic benefits stemming from investment in the technology). There is evidence that even subtle differences in framing can have large effects of stated preferences (Chong and Druckman, 2007). For example, preferences for 'shale oil and gas development' are observed to be stronger than for 'fracking', despite these terms referring to the same technology (Evensen et al., 2014). Relatedly, while the information provided in the current study did consider both the advantages and drawbacks of gasification, the depth of detail provided was fairly limited. As such, there is the question as to whether peoples' attitudes might differ if they were to be exposed to more information and/or different perspectives on gasification.

4.2.3. Study context and representativeness

The current study assessed public attitudes in two industrialised, Western European democracies. Due to the recognised importance of socio-political and geographical context to perceptions of industrial technologies, caution should be exercised if seeking to generalise the findings beyond the UK and Germany. Also, one should not automatically assume that the general attitudes recorded in this study will necessarily translate into local endorsement of community-level facilities (Bell et al., 2013; Jones and Eiser, 2010). Future research could usefully contrast the attitudes registered within the current context with those from other nations engaged in industrial scale coal gasification (e.g., China, South Africa, India) and/or where deployment of waste gasification is being progressed (e.g., Holland, USA). Moreover, future studies should seek to explore the opinions of publics living within communities hosting, or earmarked to host, gasification facilities.

4.2.4. Change in self-claimed knowledge

Finally, it is noteworthy that self-claimed knowledge about gasification improved significantly more as a result of exposure to the infomercial in Germany than in the UK. We hypothesise that this is because German participants initially had more substantial misconceptions about the technology, potentially due to the negative connotations associated with the term 'gasification' ('vergasung') in Germany. As such, there was more opportunity for the infomercial to correct these misconceptions and enhanced people's self-claimed awareness in Germany vs. the UK. It will be useful for future research to investigate this hypothesis (e.g., by analysing the automatic associations that people make with the term 'gasification' in different national contexts), not least as this could have implications for how public engagement and communication campaigns are designed and delivered.

4.3. Implications

The findings could hold implications for public engagement and communication efforts relating to gasification technology (and potentially other forms of CR), akin to what has been observed with analogous technologies like Carbon Capture and Storage (Ashworth et al., 2015, 2012). What is observable from the study is that the infomercials were evaluated positively by participants and did improve their self-claimed knowledge of gasification. This was particularly evident in Germany where it appeared that participants were more prone to conflating gasification with incineration. While modal self-claimed knowledge in both sub-samples was still relatively low, the improvement seen following this short 3-min video is encouraging and suggests that participants were reporting from a more informed position.[3]

It is also clear that post-infomercial attitudes – especially waste gasification – were positive in both countries. Bearing in mind the importance of public acceptance for the successful market entry and sustainable operation of large-scale industrial technologies (Upham et al., 2015), the participant reaction to the infomercials in our study are likely to be of interest to gasification stakeholders. While it should not be assumed that the provision of information alone will ensure the acceptability and acceptance of all forms of gasification in all contexts (due to the limitations of the knowledge deficit hypothesis, see Sturgis and Allum, 2004); in a context where awareness and understanding is low, the provision of informative content, from a trusted source, could help to increase base understanding of the technology and help to correct mis-representations (e.g. the assumed links between gasification to incineration).

5. Conclusion

The current, exploratory study provides initial insight into public attitudes towards gasification as a form of CR. The findings indicate that publics in both Germany and the UK were generally positive to the technology when considered at the socio-political level. There was a particular preference for gasification following discussion of the use of municipal waste as a feedstock. Waste gasification was associated with greater positive affect and was more likely to be considered to be green technology and worthy of investment than coal gasification. Overall, the findings complement techno-economic evaluations of gasification technologies and have implications for the development of public engagement and communication programmes associated with the deployment and use of the technology in the transition towards a circular carbon economy. Crucially, gasification is not the first industrial-scale technology to interface with the public, and thus decision-makers would do well to learn from the lessons of the past, which attest to the benefits of developing meaningful, upstream, and inclusive forms of public engagement and communication (Kurath and Gisler, 2009; Tait, 2009).

Declaration of competing interest

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

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[3] It is recognised that the addition of a control condition (i.e., where participants did not receive an infomercial) would be required to categorically confirm that the infomercial caused the improved knowledge of gasification. However, bearing in mind the short time-lapse between the pre- and post-infomercial measures, it is relatively safe to assume that the infomercial was the cause of the change in self-claimed awareness.

Appendix A

Table A1
Direct effects and indirect effects of the path analytical mediation model.

		Standardized results			95% CI	
		Estimate	*s.e.*	*p*-Value	LL	UL
a path						
Condition	→ Tech_Risk	−0.04	0.03	.136	−0.09	0.01
Condition	→ Env_Risk	**−0.09**	0.03	.001	−0.15	−0.04
Condition	→ Worth_Invest	**0.08**	0.02	<.001	0.03	0.13
Condition	→ Green_Option	**0.19**	0.03	<.001	0.13	0.24
Condition	→ Pos_Affect	**0.13**	0.03	<.001	0.08	0.17
Condition	→ Neg_Affect	**−0.12**	0.03	<.001	−0.18	−0.06
Condition	→ Trust	0.01	0.02	.542	−0.03	0.05
b path						
Tech_Risk	→ Attitude	0.00	0.03	.932	−0.05	0.05
Env_Risk	→ Attitude	−0.01	0.02	.819	−0.05	0.04
Worth_Invest	→ Attitude	**0.25**	0.03	<.001	0.20	0.32
Green_Option	→ Attitude	**0.09**	0.03	<.001	0.04	0.14
Pos_Affect	→ Attitude	**0.25**	0.03	<.001	0.20	0.30
Neg_Affect	→ Attitude	**−0.14**	0.02	<.001	−0.19	−0.10
Trust	→ Attitude	**0.15**	0.03	<.001	0.09	0.21
c path						
Condition	→ Attitude	**0.08**	0.02	<.001	0.04	0.12
c′ path						
Condition	→ Attitude	−0.00	0.01	.778	−0.03	0.02

Notes. 95% CI = boundaries of the 95% confidence interval; LL = lower level; UL = upper level; s.e. = standard error; *p*-value = significance level (significant effects are in bold). Video evaluation and nationality were included as covariates.

Appendix B. Supplementary information

Supplementary information to this article can be found online at https://doi.org/10.1016/j.spc.2022.04.011.

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