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Technology for Environmental Policy: Exploring Perceptions, Values, and Trust in a Citizen Carbon Budget App

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ABSTRACT

Personal Carbon Allowances (PCAs) are a policy idea for reducing individual carbon emissions, originally proposed in the UK in the 1990s, but promptly discarded due to concerns about low public acceptability and technological limitations. Decades later, we face the global challenge of a worsened climate crisis, thus proponents of PCAs argue that they should be reconsidered. We conducted an online survey with 300 UK based participants, investigating the viability, trustworthiness, and public acceptance of a Citizen Carbon Budget (CCB) app to monitor and encourage carbon emission reduction from personal activities and the relation of responses to Schwartz's Portrait Values Questionnaire. Our findings indicate that trust in using this kind of applications should not only be focused on their technical aspects but on the preconditions of trusting the implementation of this policy. Further, we found that holding stronger social values relate to a greater willingness to contribute to minimising individual carbon emissions and consequently to use the app across the board, including greater acceptance of automated features, and willingness to trust the app and stakeholders involved; these were not the case when holding stronger personal values. Various solutions may be needed to appeal to people with different values and leanings for mitigating climate change.

CCS CONCEPTS

• **Human-centered computing** → **Empirical studies in HCI**; • **Applied computing** → *Computers in other domains.*

KEYWORDS

Personal Carbon Allowances, Citizen Carbon Budget, Personal Carbon Emissions, Trust, Values

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1 INTRODUCTION

Climate change remains one of the most pressing challenges facing our planet. With increasing global temperatures leading to more severe weather events and rising sea levels, there is an urgent need for effective strategies to mitigate greenhouse gas emissions. Particularly, technological solutions that enable individuals to monitor and manage their own carbon footprints can play a critical role. Among these strategies, Personal Carbon Allowances (PCAs), which allow users to track and reduce their carbon emissions, represent a promising intersection of technology and environmental stewardship.

PCAs were originally proposed in the UK in the 1990s and were investigated in the early 2000s, but were promptly discarded by projected barriers such as high costs of implementation, concerns about low public acceptability, and technological limitations [10]. Over the years, many variations of PCAs have been proposed and investigated, mostly featuring equal, free and tradeable allowances periodically given to individuals to be spent with every purchase of electricity, gas, transport fuels and services [29]. Despite the potential of PCAs apps to contribute to climate change mitigation, their effectiveness largely depends on users' attitudes, adoption and engagement. Understanding the factors that could influence individuals' trust and perceptions in participating in PCAs schemes

is crucial, in particular before they can be seriously deployed and rolled-out across the population.

We conducted an online survey with 300 participants based in the UK, exploring their perceptions towards the concept of PCAs framed as a nation-wide scheme called the Carbon Budget, managed through an app, examining aspects such as citizens' acceptance of technology, perceptions of fairness, efficiency, transparency and data protection, as well as the impact of personal and social values in trust and acceptance.

Our results show that participants tended to agree that an app like CCB would benefit wider society and that they would use it if it became very popular, everyone was using it and there were adequate safeguards. The most popular motivations to use it included to help reduce utility and transport bills, and trading unused carbon budget for vouchers. Participants tended to agree they would feel comfortable with automated app features such as recommendations based on the data shared or uploaded to the app. When asked about factors involved in trusting the app, the most relevant answers related to controlling the data's further usage (e.g. being able to delete it, choosing who to share it with, controlling which data is stored and why). There was a marked preference for a voluntary scheme rather than mandatory, for the budget to be based on household circumstances rather than an equal allowance for all, and for detailed information about budget allocation to help them feel the budget was fair. Lastly, levels of trust in different entities potentially involved in the app were moderate at best, with scientists and researchers trusted the most and big tech companies trusted the least. Further, we found that holding stronger social values relate to a greater willingness to contribute to minimise climate change and use the app across the board, including greater acceptance of automated features, and trust in the app and stakeholders involved; these were not the case when holding stronger personal motivations.

We argue that trust in technology used for environmental policy (and beyond) should not only be focused on the technical aspects but on the wider context, including social norms, fairness, privacy concerns, and involvement of different stakeholders. A range of solutions may be needed to appeal to people with different needs and values and leanings for the challenge of mitigating climate change. [14].

2 RELATED WORK

2.1 Personal Carbon Allowances

The concept of Personal Carbon Allowances (PCAs) presents a unique, individualised approach to reducing carbon emissions, designed to directly engage and support citizens. Within the scheme, each adult receives an equal, tradeable carbon allowance to cover their personal travel and household energy use. The original PCAs concept, as Fawcett (2010) described, gradually reduces these allowances over time in line with national emission reduction targets [9]. This reduction ensures that individuals steadily minimise their carbon footprint, while the flexibility of trading allows those who need additional credits to buy them from others who require less.

A distinguishing feature of PCAs is its personalised approach to managing emissions, offering both accountability and flexibility through tradeable allowances. Bristow et al. (2010) identified the scheme design as crucial to its acceptability [6]. Permit allocation and revenue usage significantly affect public perception and acceptance. Zhao et al. (2021) expanded on this by exploring an innovative variation involving a Public-Private Partnership (PPP) [33]. Their proposed model integrates government subsidies with incentives from private-sector entities to encourage greater participation and compliance. This approach allows the scheme to leverage both market mechanisms and government regulations for a more comprehensive incentive structure. Lövbrand and Stripple (2011) examined PCAs from a governance perspective, emphasising the importance of carbon accounting practices in turning carbon flows and stocks into manageable, governable entities [18]. They argued that clear carbon accounting is essential for establishing accountability and ensuring that personal carbon budgets can be tracked and adjusted effectively.

Despite its potential, the PCA concept has faced critiques. Concerns about fairness, social acceptance, and political trust were raised early in its development. Fawcett (2010) noted that the UK government initially considered it "ahead of its time" due to perceived high costs and concerns about social acceptance [9]. However, subsequent research suggests that PCAs could be viewed as at least as acceptable and fair as taxation policies. Reyes-Cruz et al. (2024) examined the concept of CCB through an app deployment and critical discussions with environmental stakeholders; they found that although a CCB approach could help support awareness of personal carbon emissions, it is unfair to treat all people equally in environmental policy, regardless of their background and context [22]. Jagers et al. (2017) highlighted that trust in political institutions significantly shapes attitudes toward PCA fairness [15]. People with higher trust levels are more inclined to see the scheme as equitable and effective. Gao et al. (2022) further explored how emotions and uncertainty influence acceptance [11]. Their work revealed that political trust fosters positive emotions, increasing PCAs acceptance. Conversely, distrust and uncertainty generate negative emotions, leading to strong resistance. They found that negative emotions tend to exert a stronger impact than positive emotions, emphasising the importance of clear communication and transparency in policy design to reduce uncertainty.

2.2 Trust in Automated/Autonomous/AI-driven App features

If automated and AI-driven features are to become integral to PCA and citizen carbon budget apps, user trust becomes essential to their adoption and effectiveness. Understanding how users perceive and trust these technologies is crucial for ensuring the long-term success of these tools [20]. Trust is a multifaceted, complex and contested concept, which is beyond the scope of the current discussion [16]. Some considerations relevant to the current discussion include automated features and recommender systems, technical trust, socio-technical trust and ethical perspectives, among others [5].

Automated recommendations, such as data-driven PCA suggestions, are at the forefront of human-centered AI but can pose challenges regarding transparency, fairness, and privacy. Ge et al. (2022) highlighted that non-transparent or biased recommendations can compromise user trust due to concerns like privacy breaches and

perceived unfairness [12]. They advocated for trustworthy recommender systems that prioritise explainability, user-controllable features, and fair treatment across demographics. In a carbon budgeting context, transparent and explainable recommendations could improve user acceptance. Most importantly, transparency is needed regarding how the data collected by the app will be used to impose restrictions to its user by policymakers, what impact will have to his freedom [20].

Technical features like data collection and AI modelling can be distrusted because of the "black box" nature of some AI algorithms. von Eschenbach (2021) emphasised that deep learning algorithms often produce decisions incomprehensible to users, creating a "black box problem" [32]. This opacity erodes trust, especially in sensitive areas like healthcare and security. von Eschenbach suggested that transparency and situating AI systems within a socio-technical framework could address these concerns.

Schmidt et al. (2020) demonstrated that even transparent AI systems might not always inspire trust due to contextual factors like the presentation and support provided by stakeholders [24]. Their research indicated that too much transparency or too much information without appropriate explanation could overwhelm users, leading to mistrust. They argued that trust is not just about technical accuracy but also about how stakeholders frame and support the technology. This is particularly relevant in carbon budgeting apps, where trust in government or private institutions may influence how users perceive automated recommendations.

Bach et al. (2024) emphasised the importance of socio-ethical considerations in establishing a trustworthy environment for AI-driven systems [3]. Their findings revealed that user characteristics like familiarity with AI and previous experiences can significantly affect trust levels. Moreover, they identified socio-ethical factors such as privacy, security, and fairness as essential to designing trustworthy technical features.

Choung et al. (2023) distinguished between human-like trust and functionality trust [7]. Their research revealed that both dimensions significantly impact users' intention to use AI technologies, with functionality trust (related to perceived usefulness and ease of use) exerting a more substantial influence. For carbon budget apps, offering intuitive, user-friendly features that emphasise usefulness can foster functionality trust, improving overall user attitudes.

2.3 Values and Environmental Action

Schwartz [25] defines values as desirable and cross-contextual goals that vary in importance and serve as guiding principles for people's lives, influencing attitudes, beliefs, norms and behaviours. There are ten human values identified by the theory [27], that can be grouped into those which have a social focus (Universalism, Benevolence, Conformity, Tradition, Security) and those which have a personal focus (Power, Achievement, Hedonism, Stimulation, Self-Direction).

Past research has investigated how Schwartz' values feature or influence particular behaviours such as those related to environment-friendly lifestyles. Axsen et al. (2013) found that sustainability-oriented mindsets align with three of the ten core values proposed by Schwartz: benevolence (i.e., sustainability as helping family and friends), universalism (i.e., sustainability as saving the world), and self-direction (i.e., sustainability as personal development) [2]. Barbarossa et al. (2017) proposed a model of electric car adoption intention, in which values determined green self-identity and in turn influenced consumer intentions to adopt electric cars, both directly and indirectly (via ecological care and moral obligation motivations) [4]. Sopha and Klöckner (2011) investigated adoption of wood pellet technology for home heating and found that norms and values' influence was only minor, whereas the reliability perception and the costs were more important for adoption [30]. Ilstedt et al. (2017) investigated people with different values and their relation to sustainability in the Swedish context; they found differences in understandings of sustainable practices (e.g. underestimating or overestimating eco-friendly behaviours) and perceptions (e.g. personal responsibility vs the responsibility lies elsewhere) [14].

3 METHODS

The study was approved by the School of Computer Science's ethics committee at the University of Nottingham in the UK. In this section we describe the recruitment process, the materials and procedure employed and the data analysis.

3.1 Study participants

Participants were recruited using the Prolific[1] platform; the study was limited to people based in the UK. Participants were incentivized to take part in the survey through monetary compensation paid into their Prolific account.

A sample of 300 members of the UK population aged 18 to 78 years took part (average of 46 years old, SD=15.7). Participants were asked a set of demographic questions including gender, ethnicity, education and employment, household information, and political leanings. A summary of this information is presented in Table 1. In addition, households had an average of 2 adults (SD=1) and 1 child (SD=1) with a range of 1 to 7 adults and 0 to 4 children. 42.0% had no children in their household. On a scale of 1 to 11, where 1 is extremely left-leaning and 11 is extremely right-leaning, average response was 3.9 (SD=2.1) which is moderately left. 41.7% (n=125) reported 1 to 4 (left), 50.0% (n=150) reported 5-7 (centre), and 18.3% (n=25) reported 8-11 (right).

3.2 Materials and procedure

The online survey was carried out between March and April 2023. We employed Qualtrics[2] for the questionnaire and Prolific for participant recruitment. Participants were provided with information about the project and privacy notices, and their informed consent was gained in order for them to proceed with the survey. Questions were close-ended (multiple choice or rated on Likert-like scales), some followed by optional open-ended questions to explain or elaborate on previous answers. All the questions were presented to all participants, i.e. no branching was included in the survey. Section 1 of the questionnaire asked participants about their demographics (see Table 1); these questions were optional. Section 2 asked about participants' current environmental and budgeting behaviour. Section 3 enquired about participants' attitudes towards a hypothetical carbon budgeting app. Finally, section 4 asked participants

[1] https://www.prolific.com/
[2] https://www.qualtrics.com/uk/

Table 1: Summary characteristics of participants

Characteristic	Participants (N=300), n(%)
Gender	
Female	150 (50.0%)
Male	144 (48.0%)
Ethnicity	
White	253 (84.3%)
Asian	17 (5.7%)
Black	10 (3.3%)
Mixed	10 (3.3%)
Other	10 (3.3%)
Education	
Current student	26 (84.3%)
Not current student	244 (74.7%)
Completed:	
Primary School	1 (0.3%)
Secondary School (GCSEs or equivalent)	37 (12.3%)
Sixth form, college, or apprenticeship	78 (26%)
HNC/HND/Foundation degree	15 (5%)
Bachelor's degree	95 (31.7%)
Master's degree	40 (13.3%)
Doctoral Degree	16 (5.3%)
Professional accreditation	10 (3.3%)
No response	8 (2.7%)
Employment	
Employed full time	110 (36.7%)
Employed part time	47 (15.7%)
Not in paid work	53 (17.7%)
Unemployed and not looking	15 (5.0%)
Other circumstances	13 (4.3%)
Household location	
City centre	25 (8.3%)
City suburbs	87 (29%)
Town centre	21 (7%)
Town suburbs	98 (32.7%)
Large village (population more than 2000)	28 (9.3%)
Small village (population less than 2000)	27 (9%)
Hamlet (population less than 100)	3 (1%)
Isolated house or farm	3 (1%)
Prefer not to say	8 (2.7%)
Household income	
Less than £15,000	27 (9%)
£15,000 to £19,999	16 (5.3%)
£20,000 to £29,999	57 (19%)
£30,000 to £39,999	48 (16%)
£40,000 to £49,999	38 (12.7%)
£50,000 to £59,999	28 (9.3%)
£60,000 to £69,999	23 (7.7%)
£70,000 to £99,999	24 (8%)
Over £99,999	17 (5.7%)
No response	22 (7.3%)

to rate their personal values, and environmental understanding and attitudes.

3.3 Data analysis

3.3.1 Quantitative analysis. Descriptive and statistical analysis was conducted on the responses to the close-ended questions. Descriptives include mean and SD, and frequencies for scales.

The statistical analysis focused on three aspects: social and personal values (as explained in 2.3), and political leanings (given the political context of PCAs, as highlighted in 2.1). Results are shown in the following section, considering significant correlations above 0.4 to indicate a moderate relationship (underlined and highlighted in green in tables below), between 0.2 and 0.4 to indicate a weak relationship (between brackets and highlighted in yellow in tables below), and those below to indicate no or very weak true relationship, at a significance threshold of $p<0.05$. Pearson correlations between social vs personal values, and between values and political leanings vs opinions about the app. Note that negative correlations with political leanings indicate a relationship with higher left-wing leanings, and positive correlations indicate a relationship with higher right-wing leanings. Between subjects t-tests were employed to compare social vs personal values, and mandatory vs voluntary scheme.

3.3.2 Qualitative analysis. The qualitative data analysis was conducted on two open questions that were included in the online survey to gain a deeper understanding of trust insights in a carbon budgeting application. These two questions were:

- Is there anything else that would help you to trust a carbon budgeting app?
- Is there anything that would make you distrust an app like this?

The data was analysed by taking an inductive approach without having pre-set categories or theories. Inter-reliability check was then performed by two coders for each questions to check the agreement.

4 RESULTS

4.1 Portrait Values Questionnaire

Participants were asked to fill out the 21-item version of the Portrait Values Questionnaire developed by Schwartz [28]. The PVQ-21 presents participants with statements (or 'portraits') about people who hold a specific value and asks them to rate on a scale of 1-6 how 'like them' each one is. Reliability of the constructs is generally good, except for Self-Direction and Tradition; reliability has previously been raised as an issue of PVQ [26, 31], but because the questionnaire aims to cover the range of content of the full motivational continuum of values with a limited number of value types and items, it is impossible to have high reliability for all ten values. Results from the PVQ-21 questionnaire are shown in Table 2. The most salient values (as explained in 3.3.1) among participants were Benevolence, Universalism, and Self-direction. The least salient values were Power, Achievement, and Stimulation. A social focus is significantly stronger than a personal focus, $t(284)=14.52$, $p<0.001$. Higher social focus also correlates with a higher personal focus, $r=0.25$, $p<0.001$.

4.2 Opinions on the Carbon Budget app

Tables 3 and 4 detail responses to statements about a hypothetical carbon budget app. When asked how much they agreed or disagreed with statements surrounding the benefits of the Carbon Budget App, participants tended to agree that an app would benefit wider society (67.3%), and that it would be an effective way for the government to understand the challenges of decarbonisation for its citizens (66.7%). They were more neutral about the idea that other people would download and use the app (59%) or that they would take advice offered by the app (61%), and about whether the app would benefit them personally (53.4%). When asked about why they might participate in such a scheme, some participants indicated that they would not participate in the scheme under any circumstances (19.4%). The most popular reason for participating was if it became very popular and everyone was using it (57.7%) or if it was recommended by environmental charities (53.3%). Few agreed that they would use the app if recommended by the government (32%), or that no one else would act so they had to (25.3%).

Pearson's correlations show that all relationships between human values, political leanings, and opinions about the app are weak (highlighted in yellow in Table 3); the main relationships are to do with having higher values with a social focus. Stronger social values relate to a greater willingness to use the app across the board, especially if it was recommended by environmental charities or the government. Stronger social values also relate to believing the app would benefit society and them personally, and that it would be an effective way for the government to understand decarbonisation challenges. Greater left-wing tendencies relate to higher willingness to use the app due to environmental charity recommendations, and because they felt that others would not act, and that the app would benefit wider society. Higher personal values relate only to recommendations from environmental charities.

When asked to what extent a list of motivations would be reasons that they might use an app like this, most reasons were at least moderately appealing (Table 4). The most popular reason to use the app was to reduce utility and transport bills (63.6%). Reducing their own carbon footprint (54.7%), having a sense of control over energy use and bills (53%), understanding how their behaviour effects the environment (52%), contributing to the goal of Net-Zero (48.3%), and increasing understanding of the changes occurring due to the energy crisis (46.3%) were similarly appealing. Providing data to official organisations to monitor policy goals was not very appealing (29.7%).

In terms of app features that would encourage participants to download and use it (Table 4), the feature that would most encourage people to use the app was receiving money back for unused budget (74.7%). Participants also liked the idea of being able to trade unused budget for money-off vouchers for household items (67.3%), being able to track carbon usage over time (58%), and receiving personalised recommendations for reducing environmental impact (49%). Opinions were more mixed about trading unused carbon budget for money off entertainment (47%) and being able to convert unused budget into contributions to environmental causes or to the local area (40.3%), as well as being able to buy additional carbon budget (32%). Being able to gift unused budget to others was not popular (31.3%).

Table 2: Schwartz's Theory of Basic Values, as defined in [27], reliability, and average scores (1=not at all like me, to 6=very much like me).

Construct	Defining goal	Cronbach's alpha	Mean (SD)
Social Focus		**0.81**	**4.2 (0.7)**
Benevolence	Preserving and enhancing the welfare of those with whom one is in frequent personal contact (the 'in-group')	0.74	4.7 (1.0)
Universalism	Understanding, appreciation, tolerance, and protection for the welfare of all people and for nature	0.71	4.6 (0.9)
Security	Safety, harmony, and stability of society, of relationships, and of self	0.67	4.2 (1.1)
Tradition	Respect, commitment, and acceptance of the customs and ideas that one's culture or religion provides	0.28	3.8 (1.0)
Conformity	Restraint of actions, inclinations, and impulses likely to upset or harm others and violate social expectations or norms	0.69	3.4 (1.2)
Personal Focus		**0.84**	**3.4 (0.8)**
Self-Direction	Independent though and action; choosing, creating, exploring	0.4	4.4 (1.0)
Hedonism	Pleasure or sensuous gratification for oneself	0.75	3.4 (1.1)
Stimulation	Excitement, novelty, and challenge in life	0.72	3.3 (1.2)
Achievement	Personal success through demonstrating competence according to social standards	0.78	3.1 (1.2)
Power	Social status and prestige, control or dominance over people and resources	0.63	2.8 (1.1)

Pearson's correlations indicate that holding stronger social values moderately relates to the motivation to use the app because it would contribute to Net-Zero, and help to reduce their own carbon footprint (highlighted in green in Table 4). There are also weak-to-moderate relationships between stronger social values and having control over their energy use, increasing understanding of how their behaviour affects both the environment and the energy crisis, and being able to track carbon usage over time, reduce bills, and receive personalised recommendations for reducing environmental impacts (highlighted in yellow in Table 4). All other relationships are weak. Stronger personal values relate to the motivation to reduce bills and to trade unused budget for money off entertainment. Stronger left-wing leanings relate to the motivation to reduce their own carbon footprint, contribute to the overall goal of Net-Zero, and to be able to convert unused budget to environmental causes and to support local causes.

When asked how comfortable they would be aspects of the app being automated (Table 5), participants were most comfortable with recommendations being automated based on data uploaded to the app (59%) and with energy use being automatically uploaded to the app (58.7%). They were more split about public transport or driving data (49%) or supermarket data being automatically uploaded (47%), or about personal budgets being automatically calculated (49%). They were least comfortable with having their bank upload calculations of their carbon emissions (27.4%).

Once again, whilst all correlations were weak, the strongest (highlighted in yellow in Table 5) were between stronger social values and greater acceptance of automated features, the strongest being energy use uploads and the weakest being automated bank uploads. Stronger left-wing leanings also relate to greater acceptance of automated recommendations, transport and supermarket data being uploaded, and calculation of the personal budget being automated. Higher personal values do not relate to these features.

4.3 Trust and mistrust in the app

Participants strongly agreed that they would need to trust an app like this before they would use it (90.7% somewhat or strongly agree, mean=4.6, SD=0.8). When provided with examples of factors that may contribute to trust, all options for features that would help increase trust were received positively by participants (Table 6). The most popular suggestions were being able to delete data at any time (79%), choosing who to share data with (77.7%), and controlling which data is stored and why (77.4%). The least popular suggestions were querying recommendations (58%), finding out where data comes from (62%), and having trust in the developers of the app (64.3%).

Once again, stronger social values related to all features being considered more trustworthy (highlighted in yellow in Table 6), especially being able to find out how their carbon budget was calculated, trust in the developer of the app, being able to find out where the data about carbon consumption came from, and the ability to query recommendations. Stronger left-leaning political opinions also weakly relate to increased perceptions of trust, except for being able to opt-in and -out of features, and to query recommendations. Stronger personal values only relate to being able to opt-in and -out.

Levels of trust in different entities potentially involved in the app are moderate at best (Table 7), with scientists and researchers trusted the most (53.3%) and big tech companies trusted the least (67.3% negative response). Environmental charities (39%) and consumer rights (34.3%) groups received mixed responses. Government (12.7%), SMEs and tech start-ups (10.7%), and local councils (12%)

Table 3: Responses to statements about the app and participations; Pearson's correlations with political leanings, social values, and personal values. 1=Strongly disagree, 5=Strongly agree; * p<0.05 ** p<0.01

	% negative response (1/2)	% positive response (4/5)	Mean (SD)	Politics	Social Focus	Personal Focus
An app like this would benefit wider society	11.0	67.3	3.7 (1.1)	[-0.20**]	[0.33**]	0.15*
I think that an app like this would be an effective way for the government to understand the challenges of decarbonisation for its citizens	16.7	66.7	3.7 (1.2)	-0.14*	[0.24**]	0.10
I think that other people would take advice offered by an app like this	14.6	61.0	3.5 (0.9)	-0.04	0.16**	0.17**
I think that other people would download and use an app like this	17.3	59.0	3.5 (1.0)	0.02	0.09	0.17**
An app like this would benefit me personally	24.4	53.4	3.3 (1.3)	-0.19**	[0.31**]	0.13*
I would participate in the scheme...						
If it became very popular and everyone else was using it	23.3	57.7	3.4 (1.3)	-0.14**	[0.28**]	0.14*
If it was recommended by environmental charities	25.4	53.3	3.3 (1.3)	[-0.30**]	[0.37**]	[0.20**]
If it was recommended by the government	36.0	32.0	2.8 (1.2)	-0.07	[0.32**]	0.14
Because no one else will take action, so I have to	46.0	25.3	2.6 (1.2)	[-0.23**]	[0.22**]	0.05
I would not participate in such a scheme no matter what	66.0	19.4	2.2 (1.3)	0.18**	[-0.21**]	-0.12*

were generally not trusted. Most participants felt that scientists and researchers were best placed to roll out the app (24.7%) followed by consumer rights groups (18.0%), the government (17.7%) and environmental charities (17.3%).

Once again, those with stronger social values held more trust in each stakeholder (highlighted in yellow in Table 7), especially environmental charities, and scientists and researchers. Stronger left-leaning politics also relate to stronger trust in environmental charities, scientists, and consumer rights groups. Stronger personal values relate to increased trust in environmental charities and big tech companies.

From the open-ended responses given by participants in response to the question *"Is there anything else that would help you to trust a carbon budgeting app?"*, most respondents indicated that the technical feasibility of the application (e.g., accuracy, security, design choices) and data management (including control, storage, usage, sharing, and protection) would significantly influence their trust in a carbon budget app. Many users expressed a need for increased involvement in the app's development and a clear understanding of its operations. Concerns about data protection are paramount; the commitment to not sharing or selling data to third parties was a recurring topic, reflecting the importance of respecting user privacy. The second most prominent factor influencing trust in the application was positive reviews, whether from users, celebrities, or endorsements by companies or government entities. For instance, some respondents mentioned that they would trust the application more if it were endorsed by Sir David Attenborough, Greta Thunberg, government agencies, or energy companies. This suggests that third-party validation could play a crucial role in mitigating trust issues. Moreover, the independence of the application from political and corporate influence emerged as a pivotal factor. Respondents were particularly cautious about potential biases that might arise from associations with environmental pressure groups or government entities. Participants particularly valued apps produced by entities known for their trustworthiness. A marked preference was noted for apps operated by non-profit and non-government affiliated organisations. The credibility of the developer was further underlined by a demand for the app to be maintained by a reputable development company that provides a user interface which is both functional and aesthetically pleasing, incorporating a clean and minimalist style. Additionally, the physical design and operational functionality of the app are paramount; users favoured well-designed apps that operate smoothly and are free from bugs or poor user interfaces. It was also emphasized that the app should be free from spelling mistakes or technical flaws and offer users the ability to track progress toward clear goals, with detailed explanations of the outcomes expected upon reaching these goals. These aspects underline the impact of stakeholder trustworthiness, efficient and effective app design, and clear, goal-oriented functionality in building user trust in technology. There was also a desire for fairness in the application of the app's guidelines, not only among the general public but also among large corporations. Users expressed

Table 4: Motivations to use the app; Pearson's correlations with political leanings, social values, and personal values. 1=Not at all, 5=A great deal; * p<0.05 ** p<0.01

	% Negative response (1/2)	% Positive response (4/5)	Mean (SD)	Politics	Social Focus	Personal Focus
To help me to reduce my utility and transport bills	21.3	63.6	3.6 (1.3)	-0.17**	[0.37**]	[0.23**]
It would help me to reduce my own carbon footprint	25.6	54.7	3.4 (1.4)	[-0.20**]	**0.40****	0.15**
It would give me a sense of control over my energy use and bills	26.0	53.0	3.4 (1.3)	-0.18**	[0.39**]	0.19**
To gain an increased understanding of how my behaviour effects the environment	29.3	52.0	3.3 (1.4)	-0.16**	[0.39**]	0.19**
It would contribute to the overall goal of Net-Zero	31.3	48.3	3.3 (1.4)	[-0.25**]	**0.42****	0.17**
To gain and increased understanding of the changes occurring due to the energy crisis and other events	32.7	46.3	3.2 (1.4)	-0.17**	[0.39**]	0.15*
It would provide data to official organisations (e.g. government agencies) to help monitor policy goals	49.3	29.7	2.6 (1.4)	-0.17**	[0.31**]	0.17**
Receiving money back for unused budget	15.3	74.7	4.0 (1.3)	-0.18**	[0.28**]	0.21**
Trading unused carbon budget for money-off vouchers for household items (e.g. groceries)	21.7	67.3	3.8 (1.4)	-0.14*	[0.27**]	0.17**
Being able to track my carbon usage over time	23.6	58.0	3.5 (1.4)	-0.18**	[0.39**]	0.18**
Receiving personalised recommendations for reducing my environmental impact	32.0	49.0	3.2 (1.4)	-0.18**	[0.36**]	0.16**
Trading unused carbon budget for money off entertainment (e.g. restaurant vouchers)	35.3	47.0	3.2 (1.5)	-0.14*	[0.28**]	[0.34**]
Converting unused budget into contributions to environmental causes (for example planting trees)	38.0	43.0	3.0 (1.4)	[-0.24**]	[0.34**]	0.10
Converting unused budget into contributions to my local area (for example, to support local causes)	39.7	40.3	2.7 (1.4)	[-0.21**]	[0.29**]	0.15**
Being able to buy additional carbon budget when my needs require it	48.3	32.0	2.7 (1.4)	-0.10	[0.28*]	0.07
Being able to gift my unused budget to others	54.3	31.3	2.5 (1.4)	0.16**	[0.27**]	0.08

a need for assurance that big companies are also adhering to the same standards as individuals, which would make the system feel more just and acceptable.

The open-ended responses given by participants in response to the question *'Is there anything that would make you distrust an app like this?'* can be divided into three main themes, primarily concerning the use of data by the app, who is involved, and a rejection of apps or the scheme as a whole. Concerns were raised about the use of data by the app, including its accuracy, who (and how) it is shared with and issues of misuse, security and privacy, relating to hacking, data breaches and surveillance. Little explanation was given but responses under the use of data theme showed uncertainty about how the data would be used and suspicion of the

Table 5: Attitudes towards automated features; Pearson's correlations with political leanings, social values, and personal values. 1=extremely uncomfortable, 5=extremely comfortable; * p<0.05 ** p<0.01

	% Negative response (1/2)	% Positive response (4/5)	Mean (SD)	Politics	Social Focus	Personal Focus
Recommendations, for example suggestions on how to reduce your carbon footprint, are generated automatically based on the data shared or uploaded to the app.	21.3	59.0	3.5 (1.3)	[-0.26**]	[0.29**]	0.19**
My energy provider or smart meter automatically uploads my home energy usage to the app.	28.4	58.7	3.4 (1.4)	-0.16**	[0.31**]	0.11
The public transport I use or the car I drive automatically uploads carbon emissions data to the app.	31.3	49.0	3.2 (1.4)	[-0.25**]	[0.29**]	0.10**
My supermarket automatically uploads carbon footprint data to the app for the items I bought.	33.0	47.0	3.1 (1.4)	[-0.21**]	[0.29**]	0.14*
My personal budget, for example the amount of carbon I am allocated each month is calculated automatically based on factors such as household size and other uploaded or shared data	31.7	49.0	3.1 (1.3)	[-0.25**]	[0.25**]	0.18**
My bank automatically uploads calculations of the carbon emissions of my purchases (credit and debit card transactions) to the app.	63.0	27.4	2.4 (1.4)	-0.17**	0.19**	0.13*

motivations and reputations of those involved, particularly governments and large corporations. Additionally, the term 'budgeting' elicited concerns due to its implications of deprivation and a perceived threat to autonomy, indicating that the language used could potentially repel users wary of losing control. Linked to this, within the "who is involved" theme, participants indicated variously that if the government was involved, or big businesses (charities, environmental groups and scientists were also mentioned but much less frequently) were involved then they were more likely to distrust the app. There was often little explanation as to the reasons behind this (due to the short nature of the responses), especially in relation to the government but reasons given within this theme for distrust of businesses or large corporations included the potential for large companies to make profits from the app and data held within it and potentially use the app to display adverts. A prominent theme in response to this question was a rejection of the idea as a whole on some level, with participants responding "everything" to the question or indicating that they didn't trust apps. Where this was explained in some cases this was due to the potential use of the app for coercion or control, potentially linked with the concerns raised around who is involved and the use of data theme. Last but not the least, considerable mistrust surrounds the 'carbon budgeting' concept, viewed by some as too intrusive or a "*stealth taxation tool*". Concerns about privacy and governmental overreach were common, with fears that the technology might be used for profiling and control personal behaviours (surveillance risks). Additionally, some participants rejected the adoption of such solutions, with statements like, "*I generally distrust anything like this. I don't have a smartphone or any other smart devices*", emphasising a broader resistance to smart technology and preference for less invasive environmental management methods.

4.4 Carbon Budget scheme characteristics

When asked how comfortable they would be with the app being part of a voluntary or mandatory scheme, participants were significantly more comfortable with the carbon budget policy being a voluntary scheme rather than mandatory, t(299)=-12.36, p<0.001. Holding stronger social values is significantly weakly related to being more comfortable with the scheme being mandatory (highlighted in yellow in Table 8).

When asked how they would feel about the allocation of carbon budgets being based on certain factors (Table 9) most people felt most positive about the budget being based on household circumstances (71.6%) and most negative that it should be an equal allowance for all (21%). People were more divided on it being based on the amount of energy used in the previous year (42.7%). Both stronger left-wing leanings and holding stronger social values relate, significantly but weakly, to feeling that the budget should be based on household circumstances (highlighted in yellow in Table 9).

Table 6: Factors related to trust; Pearson's correlations with political leanings, social values, and personal values. 1=not at all, 5=a great deal; * p<0.05 ** p<0.01

Being able to....	% negative response (1/2)	% positive response (4/5)	Mean (SD)	Politics	Social Focus	Personal Focus
delete my data from the app at any time	12.0	79.0	4.1 (1.2)	[-0.20**]	[0.22**]	0.17**
choose who I share my data with, if anyone	13.6	77.7	4.1 (1.2)	[-0.22**]	[0.30**]	0.16**
control which of my data is stored, and why	12.0	77.4	4.1 (1.2)	[-0.20**]	[0.30**]	0.16**
opt-in and –out of features (e.g. receiving recommendations) at any time	17.3	69.6	3.9 (1.3)	-0.12*	[0.28**]	[0.22**]
find out how my personal carbon budget is calculated	18.0	66.0	3.8 (1.3)	[-0.21**]	[0.37**]	0.10
get extra information about any aspect of the app that I am unsure of	17.4	66.7	3.7 (1.2)	[-0.20**]	[0.35**]	0.10
trust in the developer of the app (e.g. the company or institution who released it)	18.6	64.3	3.7 (1.3)	[-0.21**]	[0.39**]	0.14*
find out where the data about carbon consumption (e.g. food miles) comes from	19.4	62.0	3.6 (1.3)	[-0.20**]	[0.34**]	0.13*
query why any recommendations are made	20.0	58.0	3.6 (1.3)	-0.18**	[0.33**]	0.13*

Table 7: Trust in stakeholders, and Pearson's correlations with political leanings, social values, and personal values. 1=not at all, 5=a great deal; * p<0.05 ** p<0.01

	% negative response (1/2)	% positive response (4/5)	Mean (SD)	Politics	Social focus	Personal focus
Scientists and researchers	25.0	53.3	3.4 (1.2)	[-0.31**]	[0.31**]	0.18*
Environmental charities and organisations	34.3	39.0	3.0 (1.2)	[-0.35**]	[0.36**]	[0.23**]
Consumer Rights groups (e.g., Which?)	36.3	34.3	2.9 (1.2)	[-0.25**]	[0.24**]	0.08
Your local council	58.7	12.0	2.3 (1.0)	-0.13**	[0.22**]	1.12*
Small-to-medium enterprises and technology start-ups	61.3	10.7	2.2 (1.0)	-0.13*	[0.22**]	0.17**
The UK Government	63.7	12.7	2.2 (1.2)	0.05	[0.22**]	0.14**
The big tech companies, such as Google and Apple	67.3	14.0	2.1 (1.2)	-0.09	[0.22**]	[0.22**]

The most common suggestions for other things that a budget should be based on (open-ended question) revolved around household income (n=40) and how many people there are in the household (n=17). Other suggestions were around the location and type of area lived in (n=7), day-to-day energy used (n=6) as well as a few other rarely suggested factors.

When asked to what extent they thought certain factors would help them to feel that the budget was fair (Table 10), most people felt that being able to get detailed information about why they have been recommended a specific budget would help (69%). They were less convinced by being able to compare their carbon footprints with others (43.3%). Comparing their budget to others was also moderately received (35.3%). Stronger left-wing leanings relate to increased perceptions of fairness when given detailed explanations (highlighted in yellow).

Table 8: Mandatory vs voluntary; Pearson's correlations with political leanings, social values, and personal values. 1=extremely uncomfortable, 5=extremely comfortable; * p<0.05 ** p<0.01

	% negative response (1/2)	% positive response (4/5)	Mean (SD)	Politics	Social Focus	Personal Focus
a mandatory scheme for all households in the UK	50.4	34.7	2.7 (1.3)	-0.18**	[0.25**]	0.13*
a voluntary scheme households can choose to take part in and opt out at any time	14.3	74.0	3.9 (1.1)	-0.08	0.12*	0.08

Table 9: Attitudes towards how the budget should be decided; Pearson's correlations with political leanings, social values, and personal values. 1=extremely negative, 5=extremely positive; * p<0.05 ** p<0.01

	% negative responses (1/2)	% positive responses (4/5)	Mean (SD)	Politics	Social Focus	Personal Focus
an equal, fixed allowance for all households	55.0	21.0	2.4 (1.1)	-0.03	0.15*	0.10
Household circumstances (e.g. additional travel needs, poor housing, disability needs)	13.7	71.6	3.8 (1.1)	[-0.32**]	[0.24**]	0.07
the amount of energy the household used in the previous year	28.7	42.7	3.1 (1.1)	-0.12*	0.16**	0.16**

Table 10: Budget fairness, and Pearson's correlations with political leanings, social values, and personal values. 1=not at all, 5=a great deal; * p<0.05 ** p<0.01

	% negative response (1/2)	% positive response (4/5)	Mean (SD)	Politics	Social Focus	Personal Focus
Compare my budget to other people's budget	18.7	35.3	2.9 (1.3)	-0.10	0.11	0.05
Compare my carbon footprint to other people's carbon footprint	31.3	43.3	3.1 (1.3)	-0.12*	0.16*	0.09
Get detailed information about why I have been recommended/assigned a specific budget	15.6	69.0	3.8 (1.3)	[-0.23**]	0.19**	0.05

5 DISCUSSION

5.1 The role of social and personal values in accepting and trusting a Carbon Budget App

Although moderate or weak, social values were the most prominent across the survey responses, aligning with notions of sustainability-oriented values [2]. This suggests that people with stronger social values could be more likely to accept and adopt a carbon budget app. We found that holding stronger social values could be related to being more open to different scheme characteristics, app features and stakeholders involvement, as well as being more comfortable with the scheme being mandatory. Socially-oriented people could be more willing to accept intrusive technologies in their daily lives, including being more willing to undertake privacy risks and more open to use new automated features, which has been observed before when a clear benefit is perceived [23], in this case, helping the goal of Net-Zero and benefiting wider society. Our results also stress the importance of social norms influencing sustainable behaviours [13], as for instance, the most popular reason for participating in the app scheme was if it became very popular and everyone was using it. Additionally, there was a significant desire for the data controller to be a trusted organisation, with many users advocating for an operating scheme independent of direct governmental control, suggesting a preference for management by society itself (see 5.2). These insights underscore the impact of social values such as transparency, societal oversight, and community engagement on the acceptance and trust in the carbon budget app.

Perhaps unsurprisingly, our survey results indicate that (although

weakly) people with left-wing leanings are more open to accept and adopt a Carbon Budget app, including automated recommendations and calculations, as well as sharing data (e.g., transport, supermarket) for these purposes. Motivations were mostly related to a general preoccupation for the environment (e.g., reducing their carbon emissions, contributing to the Net-Zero goal) [19]. Left-wing leanings often overlapped with stronger social values [17], motivated by benefiting wider society and sharing the view on fairness (i.e., allocating the budget based on household circumstances).

Overall, holding stronger personal values indicated less support towards a carbon budget app. Our results suggest that people with stronger personal values could be more reticent to get on board with nation-wide schemes to reach the Net-Zero goal, unless there are clear personal benefits such as reducing bills and getting rewards. Being able to opt-out and involvement of environmental charities/organisations and Big Tech were the main factors involved in trusting the app when holding stronger personal values. Interestingly, the latter contradicts the general sentiment of distrust towards Big Tech from the majority of survey participants. Personal values such as transparency, control, and voluntary participation critically influence trust in a carbon budget app. Participants emphasized the necessity for comprehensive information about the app [23], including its developers and the handlers of the data, pointing out that a lack of transparency could deter adoption. The importance of voluntary participation was highlighted, with a preference for options that allow users to opt-out at any time without retaining their data, and a strong opposition to any compulsory usage of the app or penalties for choosing not to install it [8]. These statements underscore the need for respecting user autonomy and privacy and ensuring transparency in the app's operations to build trust among more individually-oriented people.

5.2 Trust in stakeholders influences trust in the technology

Trust in the stakeholders behind a technology significantly impacts user trust in the technology itself. Users expressed a preference for apps that are not only efficient in their intended use, but also those developed and maintained by credible organisations, which has been also highlighted by past PCA research [15]. Our results indicate that people are not distrustful of the app or system, but of who is administering it. Given the negative response in the close-ended question (Table 7) and the prominence of open-ended responses related to government or Big Tech regarding distrust, this indicates that it is not the app that is distrusted, but those running the scheme. This may mean that any scheme to help reduce carbon usage (or do anything else) may be distrusted because of government involvement, as was the situation with the UK Covid-19 app [21]. Nonetheless, it should be remarked that some open-ended responses and those with stronger personal values indicated that the government and Big Tech are trusted stakeholders. These conflicting findings indicate the complexity of values and perceptions held by different people in society, that should be taken into consideration by environmental policies and solutions. As Ilstedt et al. (2017) indicated: *"we cannot steer towards a sustainable future without grasping the full complexity of different lifestyles, values and practices"* [14, p.6]. Given that either governments or big businesses are some of those likely to be able to have the motivations or resources to implement such a scheme then this mistrust would be a significant barrier to implementing any scheme of the required scale or significance to make an impact. If these responses would be replicated across different technologies in different contexts then it appears that trust in relation to government or large companies is a prominent issue. Trust is therefore not something that is best addressed with technical implementation of scheme (e.g an app) but wider consideration of trust as a whole. If this is replicated then perhaps other ways of ensuring compliance (compulsion, regulation) are best focused on to get the desired results in issues of such importance as climate change mitigation [8]. The main implication drawn from our findings is that trust in technology should not be treated solely as a technical issue, but should be considered with regard to its wider context, i.e., seeing trust as a socio-technical issue [1], as others have established before us [3, 21, 24].

5.3 Limitations

In terms of limitations, this study sample only consisted of participants from the UK and of limited ethnic diversity. Future research should explore and compare perceptions of trust and the role of personal and social values from people in other countries. Although balanced in some characteristics (i.e. gender), participants were recruited through Prolific, so the sample may not be entirely representative of the UK population in some aspects. Moreover, the majority of responses in the survey were close-ended, with very brief open-ended responses, making it difficult to fully understand the rationale behind participants' answers, for example, concerns about government or business involvement were likely due to individual reasons beyond the scope of the survey. Furthermore, the concept of trust was assumed to be understood by participants, with no explicit explanation or exploration of trust definitions provided. Lastly, not all the 300 participants answered the open-ended questions that were analysed quantitatively, as they were optional, therefore, these findings may not necessarily reflect the perspectives of the entire sample.

6 CONCLUSION

In this paper we have presented results from an online survey with 300 participants based in the UK, exploring the viability, trustworthiness, and public acceptance of a Carbon Budget app to monitor and encourage carbon emission reduction from personal activities such as travel and energy use. We further explored the relationship of social and personal values, as well as political leanings, in accepting and trusting the app. We found that stronger social values, and to some extent left-wing leanings, can make people trust the app more and be overall more open to accept it, and to take consequential privacy risks. We also found that, conversely, stronger personal values could hinder trust in the app, and potentially other technologies managed or deployed by the government. The implications are that for social, widespread problems such as climate change, we need a range of solutions that appeal to people with different values and leanings, for instance, by focusing on different outcomes and motivations and that are managed by different stakeholders (e.g. government, Big Tech, independent environmental institutions).

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