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Effects of a carbon footprint calculator intervention on consumption and citizenship intentions and policy support: A randomised experiment☆

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ABSTRACT

Carbon footprint calculators are widely used, yet empirical evidence regarding their effectiveness remains limited. Furthermore, most existing calculators are predominantly conceptualised and designed around individual responsibilities and consumption actions. This study examines the effects of a carbon footprint calculator incorporating informational content framed to emphasise the importance of both individual and systemic changes. We employed an adjusted per-protocol analysis with randomised treatment assignment using a demographically quota-balanced online sample in Japan to estimate treatment effects among participants who completed the intervention ($N = 693$). We found that the calculator increased intentions not only for consumption actions but also for citizenship actions and policy support, potentially through spillover or synergistic effects. Specifically, citizenship action intentions, including communication, business, non-governmental, and organisational actions, increased by 9.3–18% ($p < 0.05$), while support for subsidies, regulation, and public investments also increased by 7.1–8.2% ($p < 0.05$). Although intentions for most consumption actions related to avoid, shift, and improve strategies increased by 7.7–20% ($p < 0.05$), the intervention did not produce statistically significant effects for actions requiring large investments, such as renewable energy or zero-energy housing, and for policies implying direct burdens, such as taxes or product price increases ($p > 0.05$). Estimated indirect effects through motivational factors (awareness of consequences and ascription of responsibility) were positive for both consumption and citizenship action intentions, while those through capability factors (action-related knowledge and perceived self-efficacy) were positive only for some consumption actions. Mediators and outcomes were measured at the same time, so evidence of mediation is interpreted cautiously. These findings suggest the potential usefulness of carbon footprint calculators in promoting climate citizenship action intentions and policy support, while highlighting opportunities for incorporating functions that recommend citizenship actions and their applications in participatory policymaking.

1. Introduction

Household actions have a marked effect on future emission pathways, as their consumption induces substantial greenhouse gas emissions and makes them influential stakeholders in climate policies (Dubois et al., 2019). Considering emissions across product life cycles, various mitigation opportunities exist in products and services related to housing, mobility, food, and goods (Stern and Dietz, 2020; Tukker et al., 2010). Lifestyle changes in these domains possess considerable mitigation potential (Ivanova et al., 2020; Koide et al., 2021a, 2021b) and can

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help to compensate for the insufficient technological improvements required to achieve the 1.5 °C climate target (Cap et al., 2024).

To address this challenge, carbon footprint calculators have been widely implemented in recent decades (Birnik, 2013; Mulrow et al., 2019; Padgett et al., 2008; Tiilikainen et al., 2021). These calculators assess an individual's carbon footprint and often provide customised feedback with recommended mitigation actions (Dreijerink and Paradies, 2020). Footprint calculators have attracted large numbers of users worldwide. For example, the 'Lifestyle Test' (Finnish Innovation Fund Sitra, 2024) and the Ecological Footprint calculator (Global Footprint Network, 2019) have been accessed over 1.5 million and 18 million times, respectively. Carbon footprint calculators typically combine functions to recruit users and raise awareness, facilitate footprint calculation and provide feedback, and support users in taking actions via practical advice, personal feedback, or social features (Salo et al., 2019).

Despite their widespread use, empirical evidence on the effects of carbon footprint calculators on behavioural intentions and self-reported behaviours remains limited. A review identified only a limited number of evaluation studies on footprint calculators, most of which rely on small sample sizes and lack robust evaluation designs (Dreijerink and Paradies, 2020). Among research designs, randomised experiments are considered the most robust approach, as they address biases in non-experimental studies such as before-after comparisons or post-only surveys (Bärnighausen et al., 2017; Hariton and Locascio, 2018). However, only a few studies have employed a randomised experiment to assess the overall effects of a footprint calculator relative to a no-calculator condition in the United Kingdom (Büchs et al., 2018) and the United States (Luo et al., 2023). Other experimental studies compared two types of calculators in Taiwan (Lin, 2016), or two stimuli combined with calculator use in Germany (Lasarov et al., 2024), but these studies lacked a control condition without a calculator and were limited to student samples. Other studies relied on self-selected users, including a difference-in-difference analysis in Sweden (Enlund et al., 2023) or post-hoc surveys without a control group (Aichholzer et al., 2012; Gram-Hanssen and Christensen, 2012). These studies measured either self-reported consumption, carbon footprints, or action intentions. However, the measures were commonly limited to domain-level footprints or a few selected consumption items, rather than systematically assessing a range of behavioural strategies across consumption domains and broader societal actions.

Although systemic changes and individual actions are often discussed antagonistically, both are essential for the transition to climate-neutral societies (Hampton and Whitmarsh, 2023). The role of individuals in climate change extends beyond daily consumption choices to include their influence as citizens on policy and their participation in organisations and communities (Whitmarsh et al., 2021). Individuals can influence others within and beyond their social circles, serve as role models who may shift social norms, participate in voting and direct action, invest in sustainable funds, and influence organisational decisions as managers and employees (Hampton and Whitmarsh, 2023; Nielsen et al., 2021). Public acceptance plays a critical role in increasing the political feasibility of implementing climate mitigation policies and promoting compliance with them (Drews and Van Den Bergh, 2016; Grelle and Hofmann, 2024). This raises an important question about whether interventions primarily targeting individual consumption, such as carbon footprint calculators, can also foster broader forms of societal and political climate engagement. A review study suggested that carbon footprint calculators could serve as a tool to influence broader societal engagement such as policy support and citizenship actions (Dreijerink and Paradies, 2020). However, most existing carbon footprint calculators are conceptualised and designed to promote individual consumption actions. As a result, calculator users have expressed feelings of helplessness, perceiving that individual actions cannot be taken unless broader societal constraints are addressed (Büchs et al., 2018). From an empirical perspective, their potential role in fostering broader forms of citizenship engagement and support for climate policies remains underexplored. Only a few studies in the United States have examined spillover effects on citizenship action intentions (Luo et al., 2023) or, more specifically, support for environmental groups (Mallett et al., 2013), while excluding policy support. Other studies investigating citizenship and collective actions have largely relied on interview or workshop settings (Lettenmeier et al., 2020; Vadovics et al., 2024).

From a behavioural science perspective, carbon footprint calculators may increase intentions to take mitigation actions through psychological mechanisms, including awareness of the consequences of their consumption and the personal capabilities to undertake mitigation actions (Dreijerink and Paradies, 2020). Although experimental studies can provide robust evidence on the effectiveness of calculators, the underlying mechanisms tend to remain a 'black box' because mediating effects are often not specified. Büchs et al. (2018) concluded that a footprint calculator increased general climate awareness and concerns, but the mediating effects of these factors were not examined. Other studies reported that a calculator increased carbon footprint awareness and perceived behavioural control, but they only analysed correlations with self-reported carbon footprints (Lin, 2016) or with intentions to continue using the calculator (Lin, 2017). Other studies analysed climate attitudes and responsibility (Jack et al., 2023), self-reported knowledge (Moore et al., 2026), or self-evaluations of the calculator's roles (Aichholzer et al., 2012; Collins et al., 2020), but they relied on post-surveys or workshops. The only exceptions clarifying mediating effects of psychological mechanisms specifically focused on emotional responses, such as guilt (Luo et al., 2023; Mallett et al., 2013). In short, no previous study has systematically examined the mediating mechanisms of key psychological factors related to motivation and capability, linking footprint calculator use to behavioural intentions.

Overall, previous studies have primarily conceptualised and examined carbon footprint calculators as tools for promoting private consumption behaviours, with limited attention to whether such interventions may also foster broader forms of societal and political climate engagement. In addition, research designs have been largely limited to non-experimental studies, while little is known about the psychological mechanisms underlying these effects. To address these gaps, this study examines the effects of a carbon footprint calculator that incorporated informational content framed to emphasise both individual behaviours and systemic changes. In a randomised experiment in Japan, we employed an adjusted per-protocol analysis to estimate treatment effects among participants who completed the intervention. We evaluated its effects on consumption and citizenship action intentions, as well as policy support. To better understand the underlying mechanisms, we conducted a causal mediation analysis focusing on key psychological factors identified in the literature, including motivational factors (awareness of consequences and ascription of responsibility) and capability factors (action-related knowledge and perceived self-efficacy), as mediators of behavioural intentions.

2. Literature review

2.1. Consumption behaviours and broader societal and political actions

While carbon footprint calculators primarily focus on individual consumption behaviour, environmental behaviours extend beyond consumption to a wider range of actions. Stern (2000) classifies environmentally significant behaviours into several types. The first is *private sphere environmentalism*, which concerns household consumption, including purchasing, usage, maintenance, waste disposal, and green consumerism. This category of consumption actions can be further divided into three strategies: avoid (reducing physical consumption), shift (changing consumption modes), and improve (enhancing the efficiency of products and services) (Creutzig et al., 2024). These actions vary in behavioural costs, such as time, financial expenditure, and inconvenience (Kaiser and Lange, 2021).

The remaining types of environmental behaviours extend beyond consumer roles: *environmental activism, non-activist behaviours,* and *support for public policies* (Stern, 2000). Beyond consumption, individuals can influence climate outcomes through their roles as citizens. Environmental citizenship refers to individual and collective actions to participate in society as agents of change (European Network for Environmental Citizenship, 2018). Policy support or policy acceptance describes attitudes towards the approval of environmental policies and the willingness to accept associated financial or behavioural costs (Drews and Van Den Bergh, 2016). These forms of engagement differ in that environmental citizenship involves a more active role in taking action, whereas policy support represents a more passive expression of approval or acceptance. While carbon footprint calculators are primarily designed to promote individual consumption actions, they may also have the potential to facilitate engagement with broader systemic changes by increasing policy support (Dreijerink and Paradies, 2020) and citizenship actions (Luo et al., 2023; Mallett et al., 2013).

Engaging in environmental action typically involves multiple stages, from problem awareness and goal formation to the implementation of specific actions. The Stage Model of Self-regulated Behavioural Change (SSBC) distinguishes between the pre-decision stage, in which individuals become aware of the problem and formulate a *goal intention* (e.g., reducing emissions from mobility), and the pre-action stage, in which individuals select the most suitable behaviour and formulate a specific *intention towards an action strategy* (e.g., shifting transport modes for commuting), both of which serve as preconditions for taking action (Bamberg, 2013a, 2013b). Although such a distinction between behavioural strategies and goal intentions has not been considered in previous footprint calculator studies (Büchs et al., 2018; Enlund et al., 2023; Lin, 2017), this distinction is relevant to carbon footprint calculators. These calculators typically motivate users to reduce their carbon footprints, thereby facilitating the formation of goal intentions, and subsequently recommend specific actions to mitigate their impacts, supporting the formation of action-strategy intentions.

Building on this theoretical background, this study distinguishes three types of individual engagement with climate mitigation: *consumption actions*, *citizenship actions*, and *policy support*. For consumption and citizenship actions, we further distinguish between *goal intentions* (intention to reduce emissions within specific domains, such as housing, mobility, food, and goods/services, or to engage broadly with stakeholders in the case of citizenship) and *behavioural intentions* (for specific action strategies, such as saving energy at home or donating to environmental organisations). This leads to the following hypothesis:

Hypothesis 1. Engagement with a carbon footprint calculator that incorporated informational content framed to emphasise both individual behaviours and systemic changes increases goal and behavioural intentions related to consumption and citizenship actions, as well as support for climate policies.

2.2. Psychological mechanisms of carbon footprint calculators

Carbon footprint calculators can be broadly classified as a type of eco-feedback technology, referring to technology that provides feedback on behaviours to reduce environmental impacts. In general, eco-feedback technology is based on the hypothesis that people lack understanding and awareness of their behaviours and their impacts on the environment (Froehlich et al., 2010). Typical carbon footprint calculators incorporate several behavioural change techniques, including providing personalised information on the consequences of behaviour, personal goal setting, instruction on how to perform the behaviour, social comparison, and/or self-monitoring (Dreijerink and Paradies, 2020; Michie et al., 2011a). Among these behavioural change techniques, the calculator used in the present study focuses on personalised information, goal setting, and instruction on how to perform the behaviour. According to a systematic review, these techniques are expected to influence psychological mechanisms including beliefs about consequences, knowledge, perceived capabilities, goals, and intention; which can be grouped into two categories: motivational and capability factors (Carey et al., 2018; Michie et al., 2011b). Accordingly, in the present study, we focus on these two groups of psychological mechanisms underlying the effects of carbon footprint calculators and formulate Hypotheses 2 and 3, as follows.

The first group of psychological mechanisms consists of motivational factors, which could be mainly driven by the personalised estimation and feedback of individual carbon footprints. Specifically, the Value-Belief-Norm (VBN) theory (Stern et al., 1999) provides a framework for understanding motivational mechanisms, highlighting the roles of awareness of consequences and ascription of responsibility as antecedents to pro-environmental personal norms and behaviours. Here, *awareness of consequences* reflects an individual's cognition regarding the negative environmental impacts of their behaviours, while *ascription of responsibility* captures feelings of obligation and accountability for the adverse consequences of one's actions (Schwartz, 1977). In the present study, rather than testing the full sequential model, we focus on these two key constructs and their individual mediating effects. In particular, Stern et al. (1999) suggest that these constructs activate not only consumption behaviours but also citizenship actions and policy support. Previous studies showed that a footprint calculator increased awareness of carbon footprints (consequences of consumption) (Lin, 2016) and guilt (related to responsibility, but representing a more emotional concept) (Luo et al., 2023; Mallett et al., 2013). However, their mediating effects across multiple domains of consumption and citizenship action intentions were not systematically examined. This leads to the following hypothesis:

Hypothesis 2. The effects of carbon footprint calculator interventions on consumption and citizenship action intentions are mediated through awareness of consequences and ascription of responsibility.

The second group of psychological mechanisms underlying the effects of carbon footprint calculator use would be capability factors, including action-related knowledge and perceived self-efficacy, which could be mainly driven by personalised recommendations of mitigation actions. Environmental knowledge has been distinguished into *system knowledge* (knowledge about environmental problems), *action-related knowledge* (knowledge about behavioural options), and *effectiveness knowledge* (knowledge about relative environmental benefits of behaviours) (Frick et al., 2004; Kaiser and Fuhrer, 2003). The present study focuses on perceived action-related knowledge, also referred to as *knowledge of action strategies* (Hines et al., 1987), as the form of knowledge most likely to be influenced by personalised recommendation functions. Apart from knowledge, in the context of specific actions, *perceived self-efficacy* refers to "beliefs in one's capabilities to organize and execute the course of action" (Bandura, 1998), which may be enhanced by making recommended mitigation actions more concrete and personally relevant to users. In the present study, self-efficacy was operationalised as the perceived ease or difficulty of performing specific actions, which represents the self-efficacy component of perceived behavioural control (Ajzen, 2002). Although carbon footprint calculators mostly emphasise consumption actions, the present study's calculator, which incorporates informational content framed to emphasise the importance of both individual and systemic changes, could potentially enhance individuals' capability to engage in citizenship actions. Previous studies showed that a footprint calculator increased self-reported knowledge (Moore et al., 2026) and perceived behavioural control (Lin, 2016). However, their mediating effects across multiple domains of consumption and citizenship action intentions were not systematically examined. This leads to the following hypothesis:

Hypothesis 3. The effects of carbon footprint calculator interventions on consumption and citizenship action intentions are mediated through action-related knowledge and perceived self-efficacy.

3. Methods

3.1. Overview of the carbon footprint calculator and treatment

This study used a carbon footprint calculator, '*Jibungoto*-planet', co-developed by some of the authors as a civic tech project involving volunteer engineers and designers (Koide et al., 2025). '*Jibungoto*' is a Japanese expression meaning "making it your own problem." Since its launch in August 2022, almost 60,000 users have voluntarily used this calculator. The data and estimation methods were based on previous studies (Koide et al., 2021a, 2021b), and the source code of the calculator is publicly available in a GitHub repository (Code for Japan, 2022).

This study examines the effects of an intervention that includes three sub-functions of the footprint calculator: carbon footprint estimation and feedback, personalised consumption action recommendations, and informational content highlighting the roles of both behavioural change and systemic change. These sub-functions are embedded in the aforementioned calculator, which has been publicly implemented in real-world settings since 2022. Although footprint estimation, action recommendation, and information provision focusing on consumption are typical functions of existing carbon footprint calculators worldwide (Dreijerink and Paradies, 2020; Salo et al., 2019), this calculator extended the informational content to emphasise the importance of systemic change through stakeholder actions and citizenship engagement. This represents a design advancement to address potential feelings of helplessness associated with solely emphasising individual actions identified in previous calculator studies (Büchs et al., 2018; Dreijerink and Paradies, 2020). Because these sub-functions are integrated within a single calculator experience, the present study evaluates their combined effects and does not seek to isolate the individual contribution of each sub-function.

The overall user flow of the carbon footprint calculator is included in Fig. S1 in Supplementary information (SI) 1. During the intervention, participants first read a brief explanation of the importance of tackling climate change and individual actions (the translated script is provided in Section 1.3 in SI 1). After agreeing to the calculator's terms of service, participants selected one of four domains: housing, mobility, food, or goods/services (Fig. 1b). Participants then completed carbon footprint estimation by answering up to 10 questions in the domain (Fig. 1c). Questions included categorical options (e.g., size of housing, type of vehicle, frequency of meat consumption, expenditure level on goods) and numeric inputs (e.g., amount of electricity consumption, distance travelled by vehicle and public transport). National or regional average values were used for consumption items for which users selected the "I don't know" option. The calculator then presented a personalised estimate of carbon footprints and comparisons with the national average calculated in the previous study (Koide et al., 2021a) (Fig. 1d). Participants were subsequently presented with recommended decarbonisation actions and personalised mitigation potentials, and were asked to select one or more actions (Fig. 1e). Recommended actions were shown to users in order from the highest personalised mitigation potential to the lowest (a list of 34 actions is included in Table S3 in SI 1), with irrelevant options excluded (e.g., the renewable energy option was not shown to the users who were already using renewable energy). During the selection of actions, participants could modify the intended implementation rate for actions that could be partially adopted by selecting one of four implementation levels (25%, 50%, 75%, or 100%). This commitment (pledge) could be kept private or shared publicly by posting on social networks, a practice that has been demonstrated to effectively increase environmental actions (Van Der Werff et al., 2019). After completing a domain, participants returned to the domain selection page and could proceed to any other domain. Finally, participants read a summary highlighting the importance of systemic changes, encouraging citizenship actions, and describing the roles of different stakeholders — however, in contrast to consumption actions, this component did not include interactive elements (translated script is included in Section 1.4 in SI 1).

To ensure meaningful engagement with the intervention, participants were required to complete at least two domains of the carbon footprint estimation, select at least one action in each consumption domain, and view the informational content. This requirement reflects typical user behaviour observed in real-world usage of the calculator, with users estimating footprints in 2.5 domains and selecting actions in 1.7 domains on average (Koide et al., 2025).

3.2. Research design and recruitment

We conducted a two-group randomised experiment and employed an adjusted per-protocol analysis to estimate treatment effects among participants who completed the intervention. Prior to the intervention, participants were randomly assigned to either a treatment group using the Japanese carbon footprint calculator '*Jibungoto*-planet' (Fig. 1b–e) or a control group that did not use the calculator. Due to the scope of the

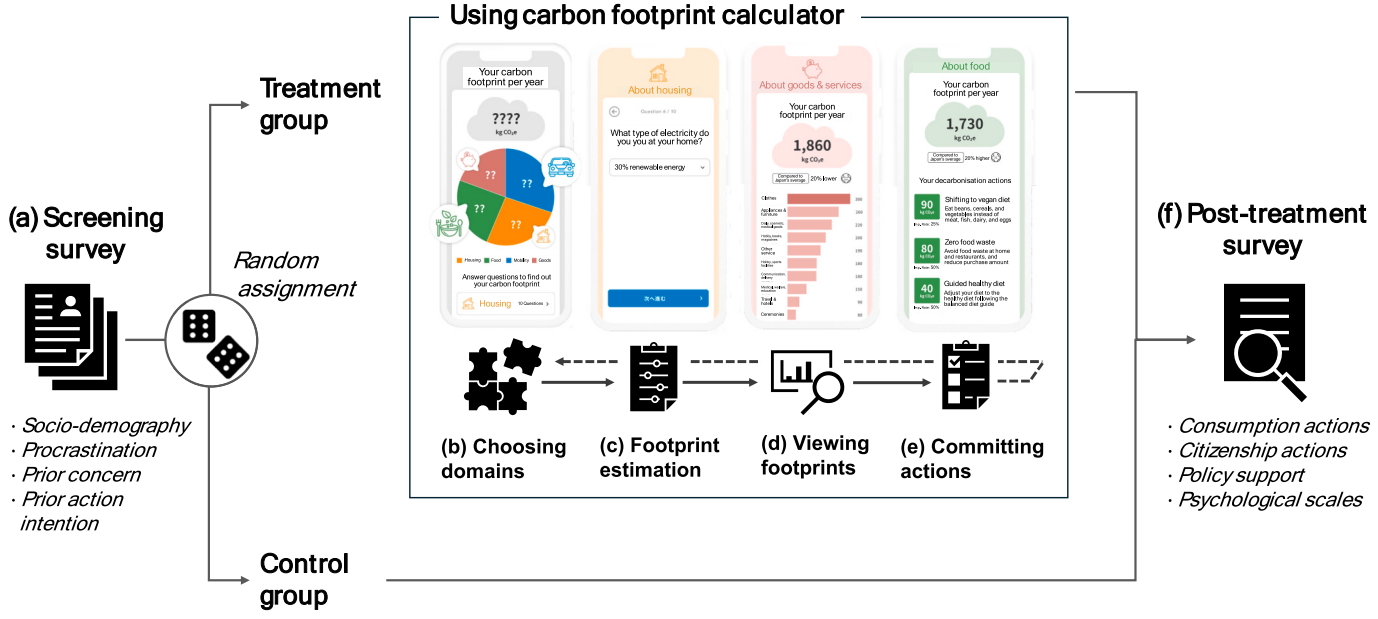


Fig. 1. Overview of research design and carbon footprint calculator.

study, which examined the effects of the full calculator within a two-group experimental design, we did not decompose the effects of individual sub-functions of the calculator; instead, the treatment group engaged with the full set of sub-functions. The analysis focuses on participants who completed the calculator tasks, as the study aims to estimate the effects of meaningful engagement with the intervention. As is common in online panel studies, non-compliance occurred, with some participants assigned to the treatment group not completing the intervention.

The survey consisted of three steps: a screening survey, the treatment, and a post-treatment survey. The screening survey was conducted on August 2–5, 2024 (Fig. 1a). Participants randomly assigned to the treatment group were then invited to use the calculator. After completing the calculator tasks, they were immediately asked to complete a post-treatment survey (Fig. 1f). Control group participants were directly invited to answer the same post-treatment survey. The intervention and the post-treatment survey were conducted during August 8–18, 2024. To compensate for the additional effort required, participants in the treatment group who completed both the calculator and the post-treatment survey received an additional incentive equivalent to 100 JPY (approximately 0.70 USD), in addition to the standard survey incentive provided to both groups. Due to the nature of the study, which employed a one-time post-treatment survey with random assignment, outcome and mediator measurements were limited to self-reported behavioural intentions, policy support, and psychological factors, all measured at a single time point immediately after the intervention.

For this study, residents in Japan aged 18 years or over were recruited and screened from a large-scale online panel using quotas stratified by age, gender, and region. At the beginning of the screening survey, participants were informed that the study might include a web-based application, although the content and purpose of the application were not disclosed. Participants were randomly assigned to treatment or control groups using block randomisation stratified by age, gender, region, and prior intention to engage in climate actions. The recruitment target was set at a minimum of 300 completed post-treatment responses in each group based on available research resources rather than a priori statistical power calculation. Given the likelihood of substantial dropout in online panel surveys, recruitment continued until the target quota composition was achieved. The screening survey consisted of 14 items, some of which were used for blocking during recruitment and as covariates in the statistical analysis (see Table 1 and Table S2 in SI 1 for survey items). The study was approved by the institutional review board (IRB) of the National Institute for Environmental Studies of Japan (Approval No.: 2024-001).

3.3. Post-treatment survey

The post-treatment questionnaire survey was designed to measure the outcome and mediator variables associated with the carbon footprint calculator intervention.

3.3.1. Outcome variables

Following Hypothesis 1, the outcome variables included intentions to engage in consumption and citizenship actions, as well as policy support. Consumption action intentions were adapted from a study on the Responsible Environmental Behaviour (REB) model (Hayward, 1990) and the VBN theory (Stern et al., 1999). The items were modified to cover 12 major actions recommended by the calculator, structured across three behavioural strategies (avoid, shift, and improve) within four domains (housing, mobility, food, and goods/services). Intentions for daily actions (e.g., saving electricity) were assessed specifically for the coming month, whereas no specific time frame was imposed for actions requiring financial investment or technological adoption (e.g., the adoption of renewable energy).

Citizenship action intentions were adapted and modified from studies on the REB and VBN theories (Hayward, 1990; Stern et al., 1999), comprising six citizenship actions covering communication, learning, stakeholder engagement (political, business, and non-governmental), and organisational actions. These items were measured as intentions within the coming year. Policy support was measured using six items adapted and modified from the VBN theory (Stern et al., 1999) and an OECD study (Dechezleprêtre et al., 2025), covering support for policy instruments (taxation, public investment, regulation, and subsidies) and willingness to accept associated burdens (increased prices and reduced living standards).

Table 1
Baseline characteristics of treatment and control groups.

Variable	Overall N = 693[a]	Treatment N = 338[a]	Control N = 355[a]	p-Value[b]
Age	48 (15)	48 (15)	49 (15)	0.7
Gender				0.3
Male	343 (49%)	163 (48%)	180 (51%)	
Female	348 (50%)	173 (51%)	175 (49%)	
Other	2 (0.3%)	2 (0.6%)	0 (0%)	
Region				0.8
Metropolitan[c]	350 (51%)	173 (51%)	177 (50%)	
Other	343 (49%)	165 (49%)	178 (50%)	
Marital status				0.6
Unmarried	300 (43%)	141 (42%)	159 (45%)	
Married/partnership	323 (47%)	160 (47%)	163 (46%)	
Divorced/widowed	70 (10%)	37 (11%)	33 (9.3%)	
Family size	2.47 (1.18)	2.49 (1.18)	2.45 (1.19)	0.7
Children age[d]	1.09 (1.97)	1.09 (1.98)	1.09 (1.97)	>0.9
Family income[e]	4.9 (2.9)	5.0 (3.0)	4.9 (2.9)	0.6
Occupation				>0.9
Permanent employment	214 (31%)	102 (30%)	112 (32%)	
Contingent employment	140 (20%)	73 (22%)	67 (19%)	
Other job	60 (8.7%)	28 (8.3%)	32 (9.0%)	
Unemployed	260 (38%)	125 (37%)	135 (38%)	
Student	19 (2.7%)	10 (3.0%)	9 (2.5%)	
Working time[f]	22 (20)	21 (20)	22 (20)	0.5
Education				0.057
Junior high school	20 (2.9%)	6 (1.8%)	14 (3.9%)	
High school	222 (32%)	100 (30%)	122 (34%)	
Technical college	14 (2.0%)	9 (2.7%)	5 (1.4%)	
Vocational school	85 (12%)	34 (10%)	51 (14%)	
Junior college	63 (9.1%)	37 (11%)	26 (7.3%)	
University	262 (38%)	138 (41%)	124 (35%)	
Graduate school	27 (3.9%)	14 (4.1%)	13 (3.7%)	
Housing tenure				0.3
Owned	459 (66%)	231 (68%)	228 (64%)	
Rented	234 (34%)	107 (32%)	127 (36%)	
General Procrastination Scale[g]	2.56 (0.75)	2.56 (0.75)	2.55 (0.76)	0.9
Prior climate change concern[h]	3.38 (1.28)	3.43 (1.25)	3.32 (1.30)	0.3
Prior climate action intention[i]	3.33 (1.11)	3.33 (1.10)	3.32 (1.12)	0.9

[a] Mean (standard deviation) for numeric variables; number of samples (proportion as a percentage) for categorical variables.
[b] One-way analysis of means (not assuming equal variances) for numeric variables; chi-square analysis for categorical variables.
[c] Prefectures in Tokyo, Osaka, and Nagoya metropolitan areas.
[d] No children (0), 0–3 years old (1), 4 years old–before primary school (2), 1st to 3rd grade of primary school (3), 4th to 6th grade of primary school (4), Junior secondary school or higher (5).
[e] Gross family income in million JPY.
[f] Weekly working hours.
[g] Mean of 13 items from Japanese General Procrastination Scale (Hayashi, 2007).
[h] Five-level Likert scale measuring concern about problems caused by climate change, adapted from a government opinion poll (Cabinet Office, Government of Japan, 2023).
[i] Five-level Likert scale measuring intention to take personal actions to reduce CO_2 emissions, adapted from a government opinion poll (Cabinet Office, Government of Japan, 2023).

In addition to behavioural intentions, goal intentions were also measured for consumption and citizenship actions based on applications of the SSBC model (Bamberg, 2013b, 2013a; Klöckner, 2017, 2014). These were measured using seven-point Likert scales across five domains in this study: four consumption domains (housing, mobility, food, and goods/services) and intentions to engage with stakeholders through citizenship actions. Behavioural intention items were measured on seven-point Likert scales ranging from 1 (*would never like to do*) to 7 (*would definitely like to do*), while policy support and goal intentions were measured from 1 (strongly disagree) to 7 (strongly agree).

3.3.2. Mediation variables

Following Hypothesis 2, *awareness of consequences* and *ascription of responsibility* were measured using both general and domain-specific items, assessed on seven-point Likert scales from 1 (*strongly disagree*) to 7 (*strongly agree*), or from 1 (*no responsibility at all*) to 7 (*high level of responsibility*), depending on the item. General items captured perceived seriousness of climate change (to oneself and one's family) and personal responsibility to prevent climate change, adapted from studies on the REB and VBN theories (Hayward, 1990; Stern et al., 1999). Domain-specific items assessed perceived causes of climate change and personal responsibility across domains (housing, mobility, food, goods/services, and citizenship/policy support), modified from previous studies (Carfora et al., 2021; Hayward, 1990).

Following Hypothesis 3, *action-related knowledge* and *perceived self-efficacy* related to individual behavioural strategies were measured. *Action-related knowledge* was measured as self-reported understanding of mitigation actions, adapted from a study on the REB model (Hayward, 1990), using seven-point Likert scales from 1 (*no knowledge at all*) to 7 (*highly knowledgeable*). *Perceived self-efficacy* was adapted from an application of the Theory of Planned Behaviour (TPB), capturing perceived ease or difficulty of performing the actions (Aguilar-Luzón et al., 2012), ranging from 1 (*very difficult*) to 7 (*very easy*).

Responses to the above questionnaire items under the same psychological mechanism were used as mediator sets in the causal mediation analysis to estimate joint natural indirect effects. These mediators were treated as complementary measures, rather than modelled as latent variables or combined into composite scores. Therefore, we examined the mediator sets from two perspectives: the coherence of each mediator set and the distinctiveness of the measurements. First, the coherence of each mediator set was assessed using Cronbach's α, McDonald's ω, and pairwise correlations (Table S4 in SI 1). Most mediator sets demonstrated acceptable internal consistency (α, $\omega \geq 0.7$), although a few mediator sets (awareness of consequences for citizenship, perceived self-efficacy for mobility and other domains) showed slightly lower values. Pairwise correlations were moderate to strong, indicating that the measures within the same mediator sets were closely related. Second, pairwise correlations among variables representing different psychological mechanisms within each domain were examined to assess the empirical distinctiveness of the proposed mechanisms (Tables S5–S9 in SI 1). Most variable combinations across different psychological mechanisms showed weak correlations ($r < 0.4$) or only moderate correlations ($r < 0.7$). Correlations among measures of the same psychological mechanism were higher than those among variables representing different psychological mechanisms, indicating the distinctiveness of the proposed measures.

3.3.3. Survey design considerations

As described in Section 3.1, participants were required to complete at least two domains. To reduce respondent burden, items on consumption behaviours were administered only for domains selected by participants. To ensure comparability with the treatment group, control group participants were asked to choose at least two domains of interest. To further reduce respondent burden, items assessing action-related knowledge and perceived self-efficacy for citizenship behaviours were limited to four categories (communication, political engagement, business-related actions, and organisational/non-governmental involvement). Due to differences in subsample sizes, statistical significance should not be directly compared across domains.

Data quality was ensured by including instrumental manipulation check questions, and only responses that passed at least two of three checks were included in the analysis (Oppenheimer et al., 2009). A full list of questionnaire items is provided in Table S1 in SI 1.

3.4. Statistical analysis

3.4.1. Effects of the carbon footprint calculator intervention

This study focuses on estimating the effects of the carbon footprint calculator intervention among participants who completed the calculator (compliers). While intention-to-treat (ITT) analysis allows us to estimate the effects of assignment (invitation to the intervention), the objective of this study is to evaluate the effects of meaningful engagement with the calculator. Accordingly, we conducted an adjusted per-protocol (complier-based) analysis (Peugh et al., 2017) to estimate treatment effects among participants who completed the intervention. To address potential bias arising from non-random compliance (Kamper, 2021), inverse probability weighting (IPW) was applied. In this approach, the probability of compliance was estimated based on covariates, and the inverse of this probability was used as weights in estimating the treatment effects (Mosquera et al., 2023).

Among the 14 variables collected in the screening survey (Table 1), seven variables that differed by compliance status or post-treatment survey completion/quality check status (gender, family income, working hours, education, housing tenure, prior climate change concern, and prior climate action intentions; see Section 4.1 for results), as well as two additional variables used to define the sampling quotas (age and region), were included in the weight estimation model. These covariates were also included in the outcome models, applying the doubly robust method (Funk et al., 2011). Treatment effects were estimated using the *WeightIt* package in R using entropy balancing (ebal) (Greifer, 2025). To account for multiple testing, *p*-values were adjusted using the Benjamini-Hochberg procedure within outcome categories specified in Hypothesis 1 (goal intentions, consumption behavioural intentions, citizenship behavioural intentions, and policy support). As supplementary analyses, we conducted analysis of variance (ANOVA) and analysis of covariance (ANCOVA) to compare the outcomes between the treatment and control groups, as well as an alternative IPW analysis in which all 14 baseline characteristics were used to estimate the weights.

3.4.2. Psychological mechanisms of carbon footprint calculators

In this study, we employed causal mediation analysis to examine the psychological mechanisms underlying the effects of the carbon footprint calculator intervention. Under the potential outcomes framework, this approach allows the decomposition of treatment effects into indirect effects mediated by psychological variables and direct effects (Pearl, 2012). As shown in Fig. 2, we hypothesised that the effects of the intervention on behavioural intentions and policy support outcomes are mediated by psychological variables, such as awareness of consequences and action-related knowledge.

This method addresses some of the limitations of traditional mediation analysis in causal interpretation, which is often susceptible to biases arising from potential confounders affecting the treatment, mediators, and outcomes (Qin, 2024). In a simple two-group experimental study, such as the one employed in this study, treatment assignment was randomised, but individual mediators were not independently manipulated. In this context, one potential issue is confounding between the mediator and the outcome; e.g., factors such as age, gender, and educational level could influence both action-related knowledge and the intention to undertake those actions. Another issue is the interaction between the treatment and the mediator; e.g., the effect of the intervention on behavioural intentions may vary depending on individual levels of belief in responsibility. Identification of the indirect effects rests

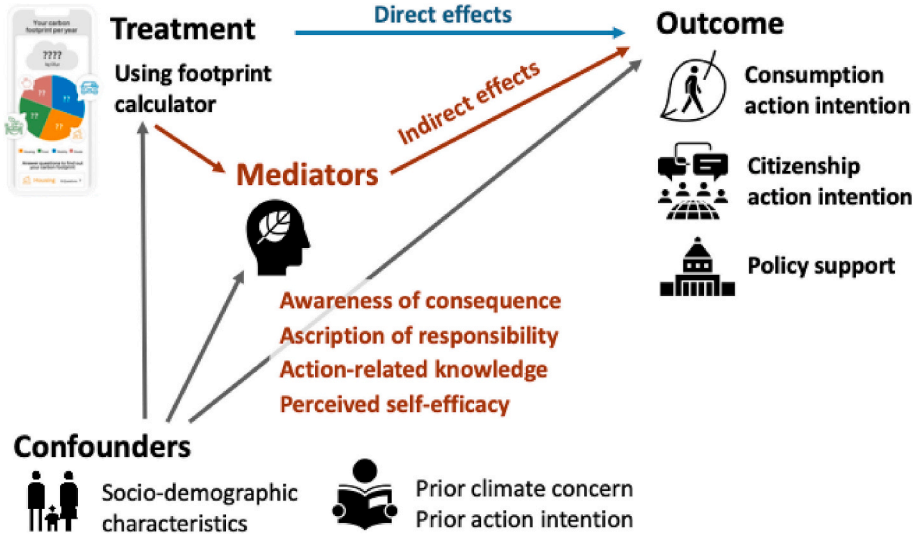


Fig. 2. Directed acyclic graph (DAG) of the causal mediation analysis. Each analysis included one outcome (e.g., energy saving, volunteering), one group of mediators (e.g., awareness of consequences, action-related knowledge), and nine confounding variables. Depending on the analysis, multiple items were used to measure each mediator construct (e.g., three items for knowledge, two for awareness of consequences), but sequential mediation effects were not considered. Confounders were measured prior to the intervention and therefore were not influenced by the treatment.

on the assumption of no unmeasured confounding of the mediator–outcome relationship conditional on the nine baseline covariates. Because treatment was randomised but the mediators were not, the mediator–outcome associations are observational. Moreover, mediators and outcomes were measured in the same post-treatment survey. Therefore, we interpret the estimates as evidence consistent with causal mediation under the stated assumptions rather than as established causal mechanisms.

The potential outcome of participant i can be expressed as $Y_i(t, M_i(t))$, where t and M refer to treatment (1 if treated, 0 if control) and potential values of the mediator given treatment, respectively. The total effect (TE) is defined as follows:

$$TE_i = Y_i(1, M_i(1)) - Y_i(0, M_i(0)) \quad (1)$$

The total effect (TE) can be decomposed into the natural indirect effect (NIE) and natural direct effect (NDE):

$$TE_i = NIE_i + NDE_i$$
$$= [Y_i(1, M_i(1)) - Y_i(1, M_i(0))] + [Y_i(1, M_i(0)) - Y_i(0, M_i(0))] \quad (2)$$

The proportion mediated (PM) is calculated as:

$$PM_i = NIE_i / TE_i \quad (3)$$

Mediation analysis was conducted separately for each outcome–psychological mechanism combination specified in Hypotheses 2 and 3. Within each combination, the relevant mediator variables (e.g., two variables for awareness of consequences, three variables for action-related knowledge) were included to estimate the joint natural indirect effect and the proportion mediated through each mediator set. Although it might be interesting to understand sequential mediation pathways (e.g., from the intervention through awareness of consequences, ascription of responsibility, personal norms, to behavioural intentions), these were not considered in this study, as no established method is currently available to quantify the individual causal effects of multiple sequential mediators (Valente et al., 2020). To account for multiple testing, p-values were adjusted using the Benjamini-Hochberg adjustment within each combination of outcome category (consumption behavioural intentions, citizenship behavioural intentions, and policy support) and mediator category specified in Hypotheses 2 and 3 (awareness of consequence, ascription of responsibility, action-related knowledge, and perceived self-efficacy). Estimation was conducted using the *CMAverse* package in R (Shi et al., 2021), with a regression-based approach and 5000 bootstrap repetitions.

4. Results

4.1. Randomisation check

The final analytic sample comprised 338 participants in the treatment group and 355 participants in the control group who completed all instructions, answered the post-treatment survey, and passed the quality checks ($N = 693$; Fig. 3). Among online panel participants randomly assigned to the treatment group and invited to use the calculator ($N = 1293$), 56% ($N = 723$) initiated use of the calculator and 75% of these participants ($N = 541$) met the minimum usage requirement. The post-treatment survey completion rates were 87% ($N = 472$ of 541) and 94% ($N = 495$ of 526) for the treatment and control groups, respectively, and 72% of participants passed the quality checks ($N = 338$ of 472, $N = 355$ of 495).

For the randomisation check, 14 baseline variables measured in the screening survey were compared between the treatment and control groups (Table 1). Despite substantial non-compliance, there were no meaningful baseline differences between the two groups, including socioeconomic characteristics and prior awareness of and intention to act on climate change. ANOVA for numerical variables and chi-squared tests for categorical variables did not show statistically significant differences between the groups ($p > 0.05$). Given the substantial attrition and the fact that the quota target was set for the completed sample, we also compared baseline characteristics at each stage of attrition: between compliers and non-compliers in the treatment group, as well as between participants who completed the post-treatment survey and passed the quality checks and those who did not in both groups (Tables S10–S12). Small but statistically significant differences were observed by compliance status for gender, family income, housing tenure, prior climate concern and climate action intentions, and by survey completion/quality check status for working time, education, and prior climate intentions ($p < 0.05$). These variables were subsequently adjusted in the IPW analysis.

4.2. Effects of the carbon footprint calculator intervention

Engagement with the carbon footprint calculator intervention, which

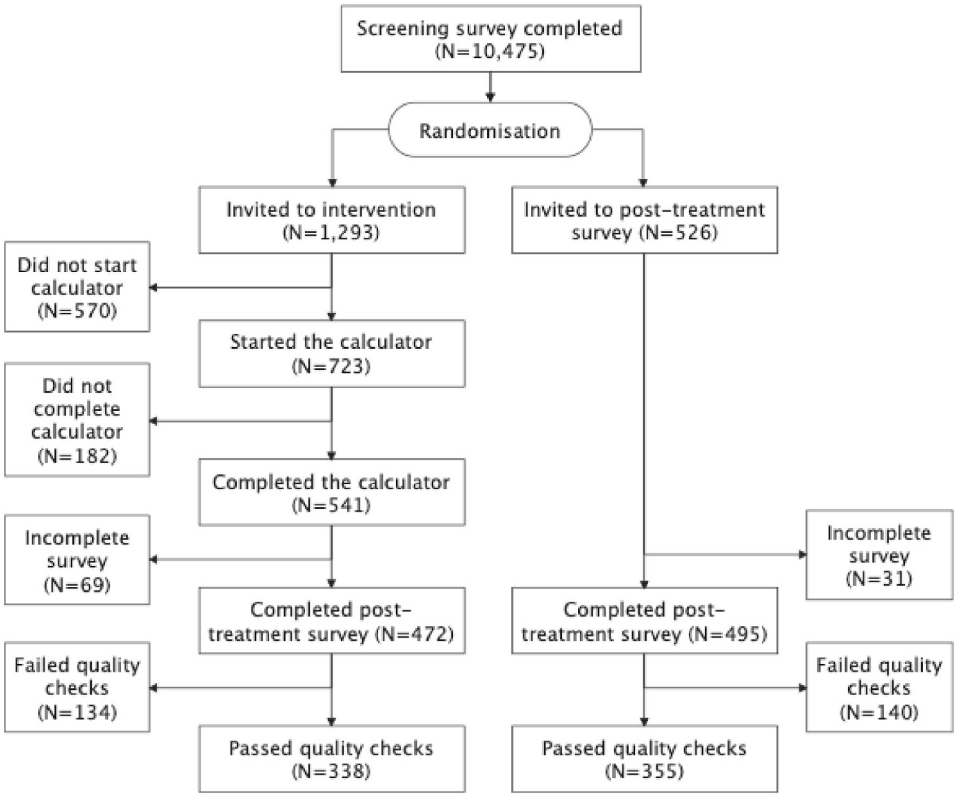


Fig. 3. Participant flow and attrition in the treatment and control groups. As participants were recruited from an online survey panel using quota sampling, the screening survey was administered to a large pool of panel members. Participants were then randomly assigned to one of the two groups and invited to participate in the study. Recruitment continued within each predefined quota category until the target sample size was reached for each category in each group.

incorporated informational content framed to emphasise both individual behaviours and systemic changes, significantly increased intentions not only for consumption actions but also for citizenship actions and policy support, consistent with Hypothesis 1 (Fig. 4). These effects were observed for both goal intentions and specific behavioural intentions. For *consumption actions*, *goal intentions* to reduce emissions increased significantly across all four domains, with relative increases of 7.9–11% (+0.35–0.47 on seven-point Likert scales, $p < 0.001$; percentages represent changes relative to the control group mean). Among specific *behavioural strategies*, calculator use significantly increased intentions for most actions by 7.7–20% (+0.26–0.79, $p < 0.05$), whereas the estimated effects for actions requiring substantial investments (e.g., *shifting to renewable energy*, *zero-energy houses/insulation*) were smaller and not statistically significant (+0.18–0.22, $p > 0.05$). The 95% confidence intervals were relatively wide (−0.17 to 0.53 and −0.13 to 0.57, respectively), as the subsample size for the housing domain was relatively small ($N = 397$). Therefore, these non-significant results should be interpreted with caution, as they are compatible with both no effect and potentially meaningful positive effects.

The intervention also significantly increased *citizenship action intentions* and *policy support*. For citizenship actions, *goal intentions* to engage stakeholders in realising a decarbonised society increased by 8.5% (+0.29 on a seven-point scale, $p < 0.01$). For specific *behavioural strategies*, intentions for *communication*, *learning*, *business-related*, *non-governmental,* and *organisational actions* increased by 9.3–18% (+0.28–0.47, $p < 0.05$), whereas the estimated effects for *political actions* were smaller and not statistically significant (+0.22, $p > 0.05$). Baseline intention levels for citizenship-related strategies in the control group were substantially lower (2.60–3.00 on seven-point scales) than those for consumption actions (3.72–5.40) (Table S13 in SI 1).

Effects on policy support varied depending on whether the policies imposed direct personal burdens. The intervention significantly increased support for *public investment, subsidies*, and *regulation* by 7.1–8.2% (+0.27–0.34, $p < 0.05$). In contrast, the estimated effects for direct burdens on citizens, such as *increased prices* or *reduced living standards* were smaller and not statistically significant (+0.12–0.13, $p > 0.05$), whereas the estimated effects for *higher taxes* was close to zero and negative (−0.01, $p > 0.05$). Baseline support levels for policies involving direct burdens were lower in the control group (2.78–3.30 on a seven-point scale) than those for policies without direct burdens (3.79–4.15) (Table S13 in SI 1). The additional IPW analysis using all 14 baseline variables, as well as the ANOVA and ANCOVA analyses, showed consistent results (Tables S14–S15 in SI 1).

4.3. Psychological mechanisms on consumption action intentions

Estimated indirect effects were consistent with two types of psychological mechanisms through which the carbon footprint calculator intervention may have influenced consumption action intentions (Table 2). For *goal intentions*, *awareness of consequences* or *ascription of responsibility* mediated 22–42% of the total treatment effects (natural indirect effects: 0.10–0.17, $p < 0.01$), consistent with Hypothesis 2. For specific *behavioural strategies*, mediation effects through *awareness of consequences* or *ascription of responsibility* were observed for most *avoid, shift, and improve* behavioural intentions related to housing, mobility, food, and goods/services for which significant total effects were observed in the previous analysis (proportion mediated: 11–48%, natural indirect effects: 0.06–0.16, $p < 0.05$). Exceptions included *longer use of products, shifting to public transport*, and *switching to electric or hybrid cars, or giving up car ownership* for which estimated mediation effects were smaller and not statistically significant, with proportion mediated of 8–15% (0.04–0.11, $p > 0.05$). Because subsample sizes differed across domains, statistical significance should not be directly compared across domains. According to the disaggregated analysis of the a-path

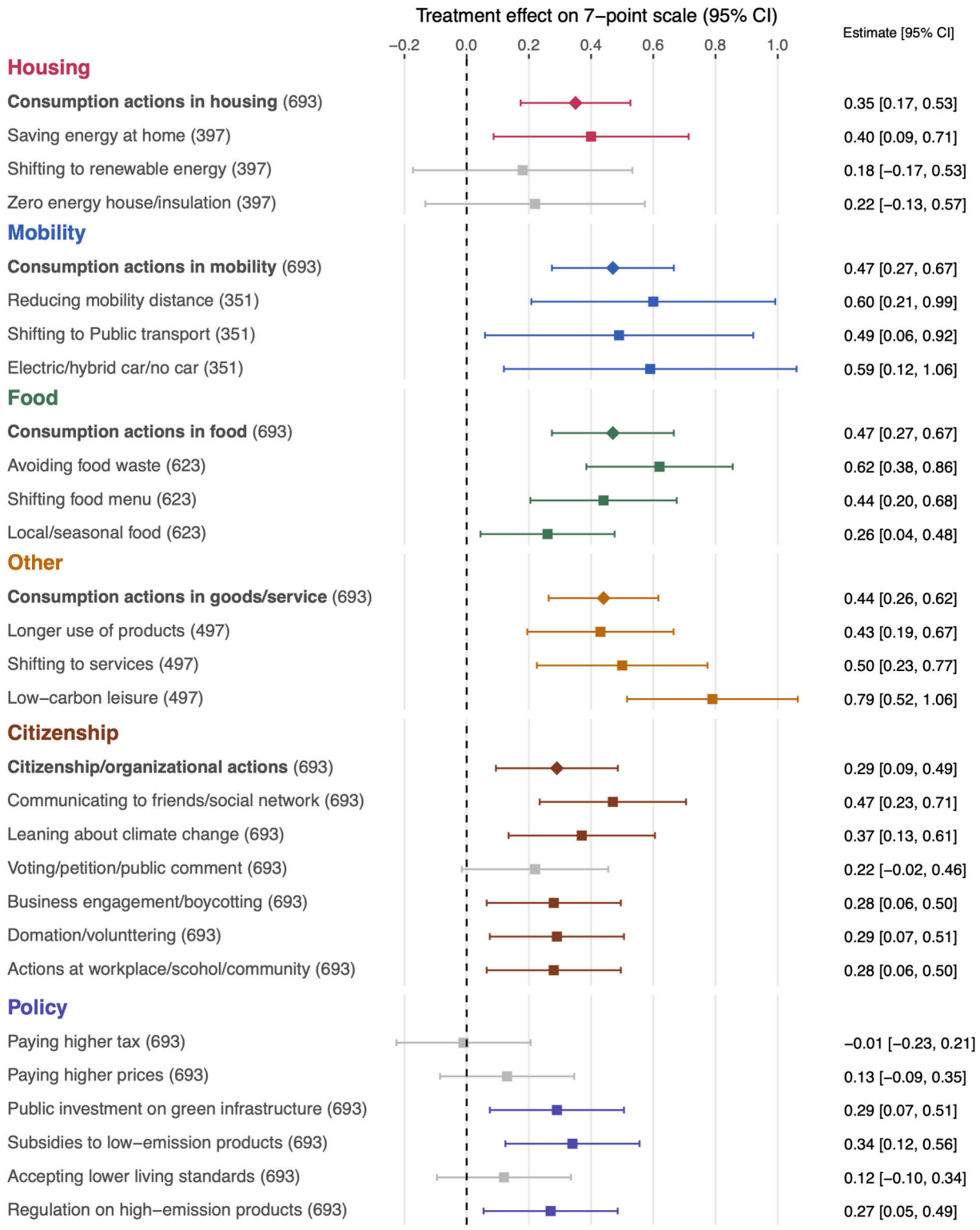


Fig. 4. Results of treatment effects of the carbon footprint calculator intervention on consumption action intentions (housing, mobility, food, and goods/services) citizenship action intentions, and policy support. Adjusted per-protocol effects of the intervention were estimated using inverse probability weighting. Nine baseline variables, namely age, gender, region, family income, housing tenure, working hours, education, prior climate concern, and prior climate action intentions, were included as covariates. The 95% confidence intervals are shown by whiskers and in brackets. Goal intentions are shown in bold and with diamond symbols, whereas behavioural intentions are shown with square symbols. The sample size for each outcome variable (sum of control and treatment groups) is shown in parentheses. Note that the sample sizes for consumption behavioural intentions varied across consumption domains. Gray markers indicate non-significant outcomes after Benjamini-Hochberg adjustment within outcome categories (goal intentions, consumption behavioural intentions, citizenship behavioural intentions, and policy support; adjusted $p > 0.05$).

Table 2
Causal mediation analysis of psychological mechanisms for consumption action intentions.

Domain/outcome	Indicator	Awareness of consequence[a]	Ascription of responsibility[b]	Action-related knowledge[c]	Perceived self-efficacy[c]
Housing					
Reducing CO_2 emissions in housing *(goal intention)*	Natural indirect effect	**0.14****	**0.12****	−0.04	−0.02
		(0.04)	**(0.04)**	(0.04)	(0.03)
	Total effect	**0.34*****	**0.34*****	**0.37****	**0.37****
		(0.09)	**(0.09)**	**(0.14)**	**(0.14)**
	Proportion mediated	42%	35%	−12%	−6%
	N	693	693	397	397
Saving energy at home *(avoid)*	Natural indirect effect	**0.16****	**0.10***	−0.04	−0.03
		(0.07)	**(0.05)**	(0.05)	(0.03)
	Total effect	**0.32***	**0.32***	**0.32***	**0.32***
		(0.16)	**(0.16)**	**(0.16)**	**(0.16)**
	Proportion mediated	48%	32%	−11%	−10%
	N	397	397	397	397
Shifting to renewable energy *(shift)*	Natural indirect effect	**0.17****	**0.14***	0.00	−0.06
		(0.06)	**(0.06)**	(0.04)	(0.06)
	Total effect	0.10	0.10	0.10	0.10
		(0.19)	(0.19)	(0.19)	(0.19)
	Proportion mediated	165%	134%	−4%	−57%
	N	397	397	397	397
Zero energy house/insulation *(improve)*	Natural indirect effect	**0.17***	**0.12***	**−0.13***	−0.05
		(0.08)	**(0.06)**	**(0.06)**	(0.05)
	Total effect	0.15	0.15	0.15	0.15
		(0.19)	(0.19)	(0.19)	(0.19)
	Proportion mediated	117%	84%	−89%	−35%
	N	397	397	397	397
Mobility					
Reducing CO_2 emissions in mobility *(goal intention)*	Natural indirect effect	**0.15*****	**0.10****	**0.11***	0.10
		(0.05)	**(0.04)**	**(0.06)**	(0.09)
	Total effect	**0.45*****	**0.45*****	**0.58****	**0.58****
		(0.10)	**(0.10)**	**(0.18)**	**(0.18)**
	Proportion mediated	33%	22%	19%	18%
	N	693	693	351	351
Reducing mobility distance *(avoid)*	Natural indirect effect	**0.14***	**0.13***	**0.13***	0.06
		(0.08)	**(0.06)**	**(0.07)**	(0.07)
	Total effect	**0.74****	**0.74****	**0.74****	**0.74****
		(0.23)	**(0.23)**	**(0.23)**	**(0.23)**
	Proportion mediated	19%	17%	18%	8%
	N	351	351	351	351
Shifting to Public transport *(shift)*	Natural indirect effect	0.09	0.08	0.07	0.26
		(0.07)	(0.06)	(0.05)	(0.14)
	Total effect	**0.61***	**0.61***	**0.61***	**0.61***
		(0.23)	**(0.23)**	**(0.23)**	**(0.23)**
	Proportion mediated	14%	14%	12%	43%
	N	351	351	351	351
Electric/hybrid car/no car *(improve)*	Natural indirect effect	0.10	0.11	0.01	−0.06
		(0.07)	(0.07)	(0.02)	(0.12)
	Total effect	**0.70****	**0.70****	**0.70***	**0.70***
		(0.25)	**(0.25)**	**(0.25)**	**(0.25)**
	Proportion mediated	14%	15%	2%	−8%
	N	351	351	351	351
Food					
Reducing climate impacts in food *(goal intention)*	Natural indirect effect	**0.17*****	**0.14*****	**0.12*****	**0.15*****
		(0.05)	**(0.04)**	**(0.04)**	**(0.04)**
	Total effect	**0.48*****	**0.48*****	**0.43*****	**0.43*****
		(0.10)	**(0.10)**	**(0.10)**	**(0.10)**
	Proportion mediated	35%	30%	29%	34%
	N	693	693	623	623
Avoiding food waste *(avoid)*	Natural indirect effect	**0.12****	**0.07***	**0.12*****	**0.20*****
		(0.04)	**(0.03)**	**(0.04)**	**(0.05)**
	Total effect	**0.64*****	**0.64*****	**0.64*****	**0.64*****
		(0.12)	**(0.12)**	**(0.12)**	**(0.12)**

(*continued on next page*)

Table 2 (*continued*)

Domain/outcome	Indicator	Awareness of consequence[a]	Ascription of responsibility[b]	Action-related knowledge[c]	Perceived self-efficacy[c]
	Proportion mediated	19%	12%	18%	31%
	N	623	623	623	623
	Natural indirect effect	**0.16*** **	**0.13*** **	**0.09** **	**0.15** **
		(0.05)	**(0.04)**	**(0.03)**	**(0.05)**
Shifting dietary choices *(shift)*	Total effect	**0.45*** **	**0.45*** **	**0.45*** **	**0.45*** **
		(0.12)	**(0.12)**	**(0.12)**	**(0.12)**
	Proportion mediated	36%	28%	20%	33%
	N	623	623	623	623
	Natural indirect effect	**0.09** **	**0.08***	**0.05***	0.06
		(0.04)	**(0.03)**	**(0.02)**	(0.05)
Local/seasonal food *(improve)*	Total effect	**0.29***	**0.29***	**0.29***	**0.29***
		(0.11)	**(0.11)**	**(0.11)**	**(0.11)**
	Proportion mediated	31%	26%	16%	20%
	N	623	623	623	623
Goods/services					
	Natural indirect effect	**0.12** **	**0.11** **	**0.14*** **	**0.13*** **
		(0.04)	**(0.04)**	**(0.04)**	**(0.04)**
Reducing climate impacts in goods/service *(goal intention)*	Total effect	**0.45*** **	**0.45*** **	**0.42*** **	**0.42*** **
		(0.09)	**(0.09)**	**(0.10)**	**(0.10)**
	Proportion mediated	27%	24%	33%	31%
	N	693	693	497	497
	Natural indirect effect	**0.10** **	0.04	**0.12** **	**0.22*** **
		(0.04)	(0.03)	**(0.05)**	**(0.07)**
Longer use of products *(avoid)*	Total effect	**0.45*** **	**0.45*** **	**0.45*** **	**0.45*** **
		(0.13)	**(0.13)**	**(0.13)**	**(0.13)**
	Proportion mediated	21%	8%	27%	49%
	N	497	497	497	497
	Natural indirect effect	**0.12** **	**0.06***	**0.06***	0.08
		(0.05)	**(0.04)**	**(0.03)**	(0.06)
Shifting to services *(shift)*	Total effect	**0.51*** **	**0.51*** **	**0.51*** **	**0.51*** **
		(0.15)	**(0.15)**	**(0.15)**	**(0.15)**
	Proportion mediated	24%	12%	11%	16%
	N	497	497	497	497
	Natural indirect effect	**0.12** **	**0.09***	**0.19*** **	**0.17***
		(0.05)	**(0.04)**	**(0.05)**	**(0.07)**
Low-carbon leisure *(improve)*	Total effect	**0.79*** **	**0.79*** **	**0.79*** **	**0.79*** **
		(0.15)	**(0.15)**	**(0.15)**	**(0.15)**
	Proportion mediated	15%	11%	23%	22%
	N	497	497	497	497

Goal intentions are indicated in bold letters, while other entries represent behavioural intentions. Standard errors are shown in brackets. Statistical significance levels after Benjamini-Hochberg adjustment within each combination of outcome category (consumption behavioural intentions, citizenship behavioural intentions, and policy support) and mediator category (awareness of consequence, ascription of responsibility, action-related knowledge, and perceived self-efficacy) are shown as $p < 0.001$***, $p < 0.01$**, $p < 0.05$*. Natural indirect effect and total effect values are highlighted in bold letters if $p < 0.05$.

[a] Combined effects from two items: awareness of climate change consequences on oneself and family, and awareness of consequences from one's own consumption in the relevant domain.

[b] Combined effects from two items: ascription of responsibility to reduce emissions in general, and responsibility for emissions from one's own consumption in relevant domain.

[c] For domain-level goal intentions, combined effects from three items: knowledge of or perceived self-efficacy over behavioural strategies (avoid, shift, and improve) in the relevant domain. For specific behavioural strategies, effects are based on a single item measuring knowledge or perceived self-efficacy for the specific action strategy.

(treatment to mediator) and b-path (mediator to outcome), these statistically non-significant mediation effects are primarily attributable to non-significant b-paths, suggesting that the intervention increased these motivational factors, but that these increases did not translate into higher behavioural intentions (Tables S16–19 in SI 1).

Mediation effects through *action-related knowledge* and *perceived self-efficacy* were primarily observed in the food and goods/services domains, partially supporting Hypothesis 3. These mediators accounted for 29–34% of the total effects on goal intentions within these two domains (natural indirect effects: 0.12–0.15, $p < 0.001$). However, these mediation effects were slightly negative in the housing domain (natural indirect effects: −0.02 to −0.04, $p > 0.05$). In the mobility domain, mediation effects were smaller, with one mediator set showing a statistically significant effect (0.11, $p < 0.05$) and the other a non-significant effect (0.10, $p > 0.05$). As noted above, statistical significance levels across domains are not directly comparable due to different subsample sizes. For specific behavioural strategies, mediation effects through *action-related knowledge* were observed for all behavioural strategies related to food and goods/services (0.05–0.19, 11–27%, $p < 0.05$), as well as for only one behavioural strategy related to mobility, namely *reducing mobility distance* (0.13, 18%, $p < 0.05$). Mediation effects were observed through *perceived self-efficacy* for

behavioural intentions such as *avoiding food waste, shifting dietary choices, prolonging product use,* and *engaging in low-carbon leisure activities* (natural indirect effects: 0.15–0.22, proportion mediated: 22–49%, $p < 0.05$). The disaggregated analysis of the a-path (treatment to mediator) and b-path (mediator to outcome) showed that these smaller or negligible mediation effects were primarily attributable to non-significant a-paths, suggesting that the intervention did not substantially increase these capability factors (Tables S16–S19).

4.4. Psychological mechanisms on citizenship action intentions and policy support

Estimated indirect effects on citizenship action intentions were consistent with mediation through beliefs regarding adverse consequences and personal responsibility, supporting Hypothesis 2 (Table 3). Awareness of consequences mediated 24–47% of the treatment effects on goal intention and all citizenship behavioural intentions for which significant total effects were observed in the previous analysis (natural indirect effects: 0.11–0.14, $p < 0.001$). Similarly, ascription of

Table 3
Results of causal mediation analysis on citizenship action intentions.

Outcome	Indicator	Awareness of consequences[a]	Ascription of responsibility[b]	Action-related knowledge[c]	Perceived self-efficacy[c]
Engage with people, government, and businesses for decarbonised society *(goal intention)*	Natural indirect effect	**0.14*** (0.04)**	**0.09* (0.04)**	0.05 (0.04)	0.02 (0.05)
	Total effect	**0.29* (0.10)**	**0.29** (0.10)**	**0.29** (0.10)**	**0.29** (0.10)**
	Proportion mediated	47%	31%	17%	7%
	N	693	693	693	693
Communicating to friends/social network	Natural indirect effect	**0.11*** (0.03)**	**0.08* (0.04)**	**0.08* (0.04)**	0.03 (0.04)
	Total effect	**0.46*** (0.11)**	**0.46*** (0.11)**	**0.46*** (0.11)**	**0.46*** (0.11)**
	Proportion mediated	24%	18%	18%	7%
	N	693	693	693	693
Learning about climate change	Natural indirect effect	**0.12*** (0.04)**	**0.09* (0.04)**	**0.06* (0.03)**	0.02 (0.03)
	Total effect	**0.37** (0.12)**	**0.37** (0.12)**	**0.37** (0.12)**	**0.37** (0.12)**
	Proportion mediated	32%	25%	17%	6%
	N	693	693	693	693
Voting/petition/public comment	Natural indirect effect	**0.11*** (0.04)**	**0.08* (0.04)**	0.08 (0.04)	0.05 (0.05)
	Total effect	0.21 (0.12)	0.21 (0.12)	0.21 (0.12)	0.21 (0.12)
	Proportion mediated	54%	40%	38%	23%
	N	693	693	693	693
Business engagement/boycotting	Natural indirect effect	**0.13*** (0.04)**	**0.10* (0.04)**	0.03 (0.04)	0.05 (0.04)
	Total effect	**0.28* (0.11)**	**0.28* (0.11)**	**0.28* (0.11)**	**0.28* (0.11)**
	Proportion mediated	47%	35%	9%	18%
	N	693	693	693	693
Donation/volunteering	Natural indirect effect	**0.11*** (0.03)**	**0.10* (0.04)**	0.02 (0.04)	−0.04 (0.05)
	Total effect	**0.30* (0.11)**	**0.30* (0.11)**	**0.30* (0.11)**	**0.30* (0.11)**
	Proportion mediated	38%	34%	6%	−12%
	N	693	693	693	693
Actions at workplace/school/community	Natural indirect effect	**0.11*** (0.03)**	**0.10* (0.04)**	0.02 (0.04)	−0.04 (0.05)
	Total effect	**0.28* (0.11)**	**0.28* (0.11)**	**0.28* (0.11)**	**0.28* (0.11)**
	Proportion mediated	37%	36%	5%	−13%
	N	693	693	693	693

Goal intentions are indicated in bold letters, while other entries represent behavioural intentions. Standard errors are shown in brackets. Statistical significance levels after Benjamini-Hochberg adjustment within each combination of outcome category (consumption behavioural intentions, citizenship behavioural intentions, and policy support) and mediator category (awareness of consequence, ascription of responsibility, action-related knowledge, and perceived self-efficacy) are shown as $p < 0.001$***, $p < 0.01$**, $p < 0.05$*. Natural indirect effect and total effect values are highlighted in bold letters if $p < 0.05$.

[a] Combined effects from two items: awareness of climate change consequences on oneself and family, and awareness of the consequences of insufficient personal citizenship actions on climate change.

[b] Combined effects from two items: ascription of responsibility to reduce emissions in general, and responsibility attributed to insufficient actions by governments and businesses.

[c] For goal intentions, combined effects from four items: action-related knowledge or perceived self-efficacy over behavioural strategies (communication, political, business, and organisational). For specific behavioural strategies, effects are based on a single item measuring action-related knowledge or perceived self-efficacy.

responsibility mediated 18–36% of the treatment effects on goal intention and all behavioural intentions for which significant total effects were observed in the previous analysis (0.08–0.10, $p < 0.05$). Conversely, action-related knowledge and perceived self-efficacy did not significantly mediate most of the treatment effects on citizenship action intentions that showed significant total effects in the previous analysis, providing only partial support for Hypothesis 3. Exceptions were communicating with friends/social networks and learning about climate change, for which action-related knowledge mediated 17–18% of the treatment effects (natural indirect effects: 0.06–0.08, $p < 0.05$). The disaggregated analysis of the a-path (treatment to mediator) and b-path (mediator to outcome) showed that the lack of mediation effects was primarily attributable to non-significant a-paths, suggesting that the intervention did not substantially increase these capability factors (Table S20). As an additional exploratory analysis, indirect effects on policy support were examined. The estimated indirect effects were consistent with mediation through beliefs regarding adverse consequences and personal responsibility for all items that had significant total effects. For example, awareness of consequences or ascription of responsibility mediated 30–56% of the treatment effects on support for public investment, subsidies, and regulation (natural indirect effects: 0.10–0.17, $p < 0.01$; Table S21 in SI 1).

5. Discussion

5.1. Effects of the carbon footprint calculator intervention across consumption and citizenship intentions, as well as policy support

This study evaluated the effects of a carbon footprint calculator incorporating informational content framed to emphasise both individual behaviours and systemic changes using an adjusted per-protocol analysis in a randomised experiment with a demographically quota-balanced online sample in Japan. A key finding is that the calculator increased intentions to engage in not only consumption actions, but also citizenship actions and support for climate policies, consistent with Hypothesis 1. Our findings showed that, although the interactive functions of the calculator only focused on personal carbon footprints and individual consumption actions, in combination with non-interactive informational content highlighting the importance of systemic change, the intervention increased intentions to engage in a variety of citizenship actions by 9.3–18%.

Positive or negative interactions across consumption and broader societal actions can be understood through two perspectives from psychology and policy sciences. Spillover effects refer to the process by which one environmental behaviour may lead to another type of behaviour, including positive spillover (an increase in another relevant behaviour) or negative spillover (a decrease in another behaviour) (Thøgersen, 1999). Literature in environmental psychology has examined spillover effects in terms of both intentions and actual behaviours (Nash et al., 2017). In contrast to spillover effects, which can explain how an intervention targeting a particular behaviour may influence non-target behaviours, synergistic effects in policy mixes refer to interaction effects among multiple interventions. When two different interventions are combined, the total effects could be larger (positive synergy), smaller (negative synergy), or equal to the sum of the two interventions (zero synergistic effects) (Alt et al., 2024; Van Den Bergh et al., 2021). Here, a particular concern regarding carbon footprint calculators is that emphasising individual responsibility and consumption could shift attention away from systemic changes (negative spillover effects), while combining interventions encouraging consumption actions and broader societal actions could undermine each other's effectiveness (negative synergistic effects). However, spillover effects related to policy support, activism, or organisational behaviours remain a crucial gap both in the broader pro-environmental behaviour literature (Behn et al., 2025) and in research on carbon footprint calculator interventions. Similarly, existing carbon footprint calculators are mostly conceptualised and designed to focus on consumption actions (Dreijerink and Paradies, 2020), and thus, integrated interventions focusing on consumption and broader societal engagement have not been explored.

The present findings imply that consumption-oriented climate engagement using a carbon footprint calculator does not necessarily undermine broader societal engagement, and may instead complement or reinforce citizenship engagement and policy support. This pattern may be explained by either spillover effects across forms of climate engagement or synergistic effects between the calculator's interactive consumption-oriented functions and non-interactive informational framing of systemic change. One possible explanation is that interactive components of the carbon footprint calculator focusing on individual consumption actions may have contributed to positive spillover effects from consumption action intentions to citizenship action intentions and policy support. Spillover effects of sustainability applications on citizenship action intentions have rarely been examined, and a few existing studies have shown mixed findings. Our findings contrast with a previous experimental study of a carbon footprint calculator in the United States, which showed non-significant spillover effects on citizenship action intentions (Luo et al., 2023), but are consistent with another study reporting significant positive effects specifically on support for environmental group (Mallett et al., 2013). Related to this, a previous survey concluded that the use of sustainability apps (not specific to carbon footprint calculators) moderates predictors of environmental citizenship behaviours (D'Arco and Marino, 2022).

Another possible interpretation is that the two components of the present study's calculator focusing on consumption actions (interactive app) and systemic change (passive information provision) may have contributed to synergistic effects. In other words, the two components may have positive synergy or at least may not have substantial negative synergy that cancelled out the effects on citizenship action intentions and policy support. However, due to the two-group randomised design, we cannot isolate the direct effects of informational content from potential spillover and synergistic effects, which remains an important topic for future research. Nevertheless, the effects in the present study appear substantial compared to a multi-country video intervention highlighting climate impacts (passive informational content) without personalised framing and footprint calculation, which increased citizenship action intentions by only +0.02 and had no significant effects on consumption action intentions (Dechezleprêtre et al., 2025). In addition, the relatively low baseline levels of citizenship engagement and the absence of effects on political action intentions observed in this study may also be related to contextual factors specific to Japan, where participation in political and collective environmental actions tends to be less common than in some Western societies.

Regarding policy support, the intervention effectively increased support for subsidies, regulation, and public investments by 7.1–8.2%. These effects on policy support appear substantial compared to information treatments specifically targeting policy effectiveness. For example, a multi-country experimental study using a video intervention reported increases of only +0.02–0.1 on five-point Likert scales for support for regulation, green investment, subsidies, and carbon taxation (Dechezleprêtre et al., 2025). A major difference between the interventions in the present study and the previous study is the use of personalised framing and interactive functions in the footprint calculator (e.g., presenting personal carbon footprints and actions that can be taken by each individual user), as opposed to non-personalised framing and non-interactive engagement through watching videos (e.g., presenting national emissions and country-level policies). Our findings imply that carbon footprint calculators incorporating personalised framing and interactive functions may be more effective in promoting citizenship action intentions and policy support.

The carbon footprint calculator intervention also increased consumption-related goal intentions by 7.9–11% and most behavioural intentions by 7.7–20%. Although only a limited number of studies have investigated the effects of calculators on consumption action intentions,

the positive effects observed here are consistent with previous studies, which showed increases in intentions related to energy, mobility, and food (Gram-Hanssen and Christensen, 2012; Luo et al., 2023; Sutcliffe et al., 2008). Nevertheless, it is important to acknowledge the well-documented intention-behaviour gap, whereby medium to large increases in intention often translate into small to moderate changes in actual behaviour (Webb and Sheeran, 2006). For example, a previous randomised experimental study found near-significant reductions in air travel and increases in walking, but no significant effects on energy use and car driving (Büchs et al., 2018). Another quasi-experimental study reported significant reductions in carbon footprints for goods/services, and near-significant reductions in transport, energy, and food domains; however, these effects were not significant after 3 months (Enlund et al., 2023). As the present study measured only goal and behavioural intentions, and few studies have examined long-term changes in actual behaviours, this remains an important topic for future research, particularly because sustainable behaviours may develop over a long period of time (Spekkink et al., 2013).

The calculator did not produce statistically significant effects for increasing behavioural intentions requiring substantial financial investment (e.g., adoption of renewable energy, zero-energy housing) or for increasing support for policies that impose direct burdens on individuals (e.g., tax increases, higher prices, reductions in living standards). The lower intention levels observed for financially demanding actions were consistent with a previous study on calculator user data (Koide et al., 2025), and with a previous experimental study which did not find significant effects on increasing intentions for reducing footprints in housing (Luo et al., 2023). This outcome could be explained by the 'low-cost hypothesis', which proposes that environmental concern is more likely to influence behaviours involving lower costs and minimal inconvenience (Diekmann and Preisendörfer, 2003). For example, investments in housing facilities typically require long-term planning, and individuals may delay such actions until opportunities arise, such as during scheduled home renovations (Stieß and Dunkelberg, 2013). In addition, as individuals require income or savings to undertake large investments, structural support, such as changes in regulations and pricing, is needed to facilitate costly actions (Gifford et al., 2011). Furthermore, the absence of statistically significant effects on increasing support for policies that impose direct burdens is consistent with previous studies, implying that people tend to prefer non-coercive 'pull' policy measures over coercive 'push' measures (Drews and Van Den Bergh, 2016).

5.2. Mediating effects of motivation and capability factors

This study went beyond a 'black box' investigation of treatment effects by estimating the psychological mechanisms. Our findings suggest that the effects of carbon footprint calculator on citizenship action intentions are associated mainly with motivational rather than capability factors. Supporting Hypothesis 2, awareness of consequences and ascription of personal responsibility mediated 11–56% of the calculator's effects on most consumption and citizenship action intentions, as well as some policy support outcomes for which significant total effects were observed in the previous analysis. Although most prior studies did not conduct mediation analyses, their findings are consistent with the present results in suggesting that footprint calculators increase concern about climate change consequences, perceptions of human responsibility (Büchs et al., 2018; Lin, 2016), and awareness of the importance of personal actions and responsibility (Aichholzer et al., 2012; Lin, 2016), as well as highlighting mediating effects of guilt on support for pro-environmental groups (Luo et al., 2023; Mallett et al., 2013). In addition, the present findings are consistent with previous review studies concluding that belief in climate change consequences (seriousness) and personal responsibility are important determinants of attitudes towards policy (Bergquist et al., 2022; Drews and Van Den Bergh, 2016).

Conversely, action-related knowledge and perceived self-efficacy mediated 11–49% of the treatment effects, mostly for consumption action intentions in the food and goods/services domains, but only partially for the mobility domain and citizenship action intentions, thus providing only partial support for Hypothesis 3. These mediation effects related to consumption actions are consistent with previous findings that the use of footprint calculators increased perceived self-efficacy, with a strong correlation being shown between self-reported carbon reductions and behavioural control (Lin, 2016). The domain-specific differences observed in mediation effects suggest that the effectiveness of these psychological mechanisms varies across types of consumption. In particular, stronger mediation effects in the food and goods/services domains may reflect the role of carbon footprint calculators in making indirect emissions more visible to users. This suggests that participants acquired greater knowledge of, and psychological capabilities for, impactful decarbonisation actions related to life cycle emissions (e.g., prolonged product use, dietary shifts) than about direct emissions (e.g., car use, household energy consumption). In contrast, limited mediation effects in the housing and mobility domains may reflect structural and contextual constraints. Actions in these domains often involve higher costs, long-term planning, or infrastructural dependencies, which may reduce the extent to which psychological capabilities translate into behavioural intentions. This interpretation is consistent with previous studies, which reported that users felt that the information provided by calculators was insufficient to enable behavioural changes (Collins et al., 2020).

For citizenship action intentions, the absence of mediation effects through action-related knowledge and perceived self-efficacy may be related to the design of the calculator. Unlike consumption actions, which were supported by interactive features such as personalised action recommendations and selection, the importance of systemic changes was only briefly presented through passive information provision. An exception was communication-related action intentions, where action-related knowledge showed a marginally significant mediation effect, potentially reflecting the calculator's built-in function that allowed participants to share their estimated footprints or committed actions on social networks. This suggests the potential for expanding carbon footprint calculators' functions to more directly encourage citizenship actions.

5.3. Collective actions and expanding the scope of footprint calculators

The present findings contribute to the ongoing debate on whether climate action strategies should target individual or collective behaviours (Anjum and Aziz, 2026). One perspective argues that individual actions do not necessarily lead to broader citizenship engagement; for example, a previous study found no evidence of behavioural spillover from personal consumption to citizenship behaviours (Lacroix et al., 2022). In addition, framing climate action at the individual level can sometimes reduce support for systemic policy changes (Chater and Loewenstein, 2023).

Conversely, other studies have suggested that promoting individual behavioural changes and changing the 'rules of the game' could be mutually reinforcing; e.g., campaigns encouraging individual action have been shown to increase public support for stringent regulations (Chater and Loewenstein, 2023). Further, reflection on personal behaviours could facilitate policy support, even for personally costly measures such as carbon taxes, when these actions are linked to their identity (Sparkman et al., 2021). Another study concluded that enhancing carbon engagement, defined as a willingness to actively engage with knowledge of climate-related social developments and political processes, may be an effective strategy for reducing footprints (Schleich et al., 2024).

The present findings provide empirical support for this latter perspective. Despite primarily focusing on individual consumption actions, the calculator intervention incorporating informational content

framed to emphasise both individual behaviours and systemic changes increased citizenship action intentions and policy support. Previous studies on user experiences with carbon footprint calculators reported that participants recognised the necessity for government support, suggesting a collective readiness to act if all stakeholders, including governments, collaborate (Büchs et al., 2018; Dubois et al., 2019; Fitzpatrick et al., 2015; Gram-Hanssen and Christensen, 2012). In addition, voluntary commitments made through footprint calculators alone are insufficient to meet climate targets, highlighting the importance of systemic changes and structural support (Dubois et al., 2019; Koide et al., 2025). Consistent with these findings, there were no statistically significant effects of calculator use on increasing intentions to undertake actions requiring substantial investments, which are typically part of a broader decision-making process (Stieß and Dunkelberg, 2013).

The present findings suggest two opportunities to extend the role of carbon footprint calculators beyond individual consumption actions. First, calculators could be enhanced to more explicitly support policy engagement, citizenship actions, and collective actions. In contrast to most recommendations from previous review studies focused on improving calculators to facilitate individual actions (Salo et al., 2019), one study recommended that calculators could facilitate collective actions to counteract feelings of helplessness among users (Dreijerink and Paradies, 2020). Such functions need not be limited to collective actions in terms of consumption (e.g., sharing used products), but could also promote individual and collective citizenship actions (e.g., participating in volunteering) (Castiglione et al., 2021). In addition, information on policy options and effectiveness could be incorporated into calculators, extending personalised framing from 'you can take action' to a collective framing that 'the system can be changed'. The present study illustrates one possible approach to frame carbon footprint calculators to encourage both individual and collective actions. Furthermore, interactive features designed to engage users with possible collective and societal actions may serve as a promising extension, potentially activating capability pathways towards citizenship actions, which were largely absent among the identified mediating mechanisms in the present study. Functions focusing on systemic change could be combined with a gamified approach (Guillén et al., 2022), collective action-tailored tools such as living labs (Laakso et al., 2021), or collaborative group training approaches (Staats et al., 2004).

Second, carbon footprint calculators could be integrated into participatory policymaking processes. The present study demonstrated that a carbon footprint calculator emphasising the importance of both individual and systemic changes increased certain citizenship action intentions and climate policy support. One possible interpretation is that learning through carbon footprint assessments may encourage citizens to reflect on and consider their potential roles in broader societal change that contribute to sustainable consumption and lifestyles. These possibilities are in line with suggestions in previous studies; footprint calculators could serve as supporting tools for consumption-based roadmapping towards decarbonised societies (Koide et al., 2021b) and for facilitating reflection on sustainable consumption and lifestyle futures (Vita et al., 2019). While several initiatives have incorporated footprint calculators into citizen workshops and thinking labs (Dubois et al., 2019; Liu and Yamabe-Ledoux, 2023; Vadovics et al., 2024), future opportunities lie in exploring their applications in participatory policymaking processes such as climate citizens' assemblies.

5.4. Limitations

This study has several limitations. First, the outcomes for consumption and citizenship actions were self-reported intentions rather than actual behaviours, and therefore, the intention–behaviour gap was not examined in this study. In addition, the outcomes were measured immediately after calculator use, and thus, the maintenance of intentions and behaviours over time was not evaluated. Because the mediators and outcomes were measured at the same time, the mediation analyses do not warrant causal interpretation. Further, the results of this study are based on a specific footprint calculator in Japan, and may require careful interpretation due to potential limitations in external validity beyond this geographic and temporal context.

Third, as this two-group study involved only one type of treatment, it was not possible to statistically distinguish the effects of individual sub-functions of the calculator, such as footprint estimation, action recommendations, and information provision. This also limits our interpretation of whether spillover effects or synergistic effects better explain the results. From a theoretical perspective, as suggested by mediation analyses, personalised and interactive features of the calculator may activate motivational factors (awareness of consequences and ascription of responsibility), which in turn influence both citizenship and consumption action intentions. In contrast, the evidence was consistent with the mediating roles of capability-related factors (action-related knowledge and perceived self-efficacy) remaining limited to some consumption actions.

Fourth, the analysis focused on participants who completed and substantially engaged with the intervention (compliers). Due to the nature of sample recruitment and study implementation using online survey panels, ITT analysis (estimating the effects of treatment assignment) was not feasible. Instead, we conducted an adjusted per-protocol analysis to estimate treatment effects among participants who completed the intervention. Accordingly, the findings should not be interpreted as the effects of inviting individuals to use the calculator, which would likely be smaller than the treatment effects among participants who completed the intervention, depending on how the intervention is implemented in real-world settings.

Finally, non-compliance rates were substantial, which is consistent with real-world implementation. Previous user data indicate drop-out rates of 9.5–48% during information provision, 5–11% during footprint estimation, and 27–43% during action recommendation (Koide et al., 2025). Although the baseline characteristics did not show any statistically significant differences between the final treatment and control samples, several variables showed small differences by treatment compliance and survey completion/quality check status. Although potential biases arising from non-random compliance were partly addressed using doubly robust adjustment with nine covariates, residual bias due to unobserved factors may remain. In addition, participants were able to self-select consumption domains, reflecting the user interface design of the calculator. Although this may introduce selection bias and domain comparisons should be interpreted with caution, it also enhances ecological validity by capturing user behaviour under realistic conditions. Despite these limitations, this study contributes to the limited body of empirical research on carbon footprint calculator interventions and their underlying psychological mechanisms, while extending the scope beyond consumption actions to include citizenship behaviours and policy support.

6. Conclusions

This study evaluated the effects of a carbon footprint calculator incorporating informational content framed to emphasise both individual behaviours and systemic changes using an adjusted per-protocol analysis in a randomised experiment. The online sample of residents in Japan aged 18 years or over was quota-matched to the Japanese population by age, gender, and region ($N = 693$). The most important finding is that the intervention increased goal intentions and behavioural intentions for both consumption and citizenship actions, as well as support for some climate policies. Our findings suggest that a carbon footprint calculator incorporating informational content framed to emphasise the importance of both individual and systemic changes can increase both consumption and citizenship action intentions, implying possible spillover or synergistic effects. These findings challenge the assumption that interventions targeting individual consumption, such as carbon footprint calculators, may shift attention away from engagement

with systemic change. Furthermore, this study advanced beyond a 'black box' evaluation by investigating the psychological mechanisms underlying these effects. Specifically, estimated indirect effects were consistent with motivational factors (awareness of consequences and ascription of responsibility) mediating the effects of the intervention on consumption and citizenship action intentions and policy support, whereas indirect effects through capability factors (action-related knowledge and perceived self-efficacy) were significant for consumption action intentions related to food and goods/services, as well as a few action intentions related to mobility and citizenship.

Future studies could investigate changes in actual consumption and citizenship behaviours, as well as the long-term maintenance of such behaviours and policy support. Such research would require baseline and follow-up measurements, and should focus on a wide range of actions, including avoid, shift, and improve strategies across several consumption domains, as examined in the present study. Furthermore, future studies could adopt multi-group experimental designs, incorporating alternative versions of the calculator with additional functions. This approach would enable further investigation of the potential for carbon footprint calculators to facilitate systemic change and/or sustain outcomes over longer periods. Overall, these findings suggest a new avenue for carbon footprint calculators as tools that can promote not only individual behavioural intentions related to consumption but also citizenship action intentions and support for some climate policies, moving beyond the dichotomy between individual and systemic change.

CRediT authorship contribution statement

Ryu Koide: Writing – original draft, Methodology, Formal analysis, Conceptualization. **Hide-Fumi Yokoo:** Writing – review & editing, Methodology, Conceptualization. **Ryo Tajima:** Writing – review & editing, Methodology, Conceptualization. **Sho Hata:** Writing – review & editing, Conceptualization. **Michael Lettenmeier:** Writing – review & editing, Conceptualization. **Cameron Brick:** Writing – review & editing, Methodology. **Jaco Quist:** Writing – review & editing, Conceptualization. **Keisuke Nansai:** Writing – review & editing, Conceptualization.

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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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Appendix A. Supplementary data

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