



Carbon footprint tracking apps. Does feedback help reduce carbon emissions?

Stefan Hoffmann^{a,*}, Wassili Lasarov^b, Hanna Reimers^a, Melanie Trabandt^a

^a Kiel University, Institute of Business Administration, Department of Marketing, Westring 425, 24098, Kiel, Germany

^b Audencia Business School, Marketing Department, 8 Route de la Jonelière, 44312 Nantes, France

ARTICLE INFO

Handling Editor: Cecilia Maria Villas Bôas de Almeida

Keywords:

Sustainable consumption
Greenhouse gas emissions
Digital tool
Green self-efficacy
Green self-identity

ABSTRACT

One of the primary issues of sustainable consumption is that many individuals are uncertain about the environmental impact of their consumption choices and, consequently, they are uncertain how to adjust their habits to consume more sustainably. Carbon footprint tracking apps (CFTAs) seek to address this information gap by continuously educating consumers on their carbon emissions. Since the effectiveness of CFTAs has not yet been investigated at all, the authors developed a CFTA to explore whether and how such applications help shape consumption behavior. Over several survey rounds, 216 participants used the application to log their consumption in four main consumption domains. The results indicate that the feedback given can help decrease carbon emissions by 23%. The impact varies by consumption category, ranging from a 12% reduction in mobility to a 35% reduction in household activities. Moreover, individual traits influence the effectiveness of CFTA usage: Perceived green self-efficacy amplifies the feedback's effect, whereas a strong green self-identity diminishes it. Based on these results, the authors guide practitioners and academics on how to employ CFTAs to foster and research sustainable consumer behavior, and the authors show how to account for inter-individual differences when endorsing such apps. Future research should probe ways to boost effectiveness in specific areas and for particular personalities.

1. Introduction

Headlines such as “Six ways to lower your carbon emissions quickly” (BBC, 2023) and “Can you reduce climate change with a credit card? What to know about buying carbon offsets” (The Wall Street Journal, 2022) illustrate that individuals and institutions seek solutions to reduce greenhouse gas (GHG) emissions and to mitigate the threat posed by global warming. Recognizing that the GHG emissions driving global warming are mostly human-made (Global Risk Report, World Economic Forum, 2020), the United Nations' sustainable development goals (SDGs, UN, 2015) call for immediate actions, such as more sustainable production and consumption (SDG #12) and climate action (SDG #13). Although several institutions suggest easy approaches to change consumer behavior (e.g., BBC, 2023; The Wall Street Journal, 2022; CBC, 2020), it has become a cliché to point out that many consumers who claim to care about the environment frequently do not act sustainably (e.g., Carrington et al., 2010; White et al., 2019; Munro et al., 2023). A crucial factor that contributes to this so-called behavior-intention gap is

the lack of information about the carbon emissions that result from each consumption choice (Joerß et al., 2021), a fact recently corroborated by a representative study in the UK (Deloitte, 2022). This is important, since the availability of information plays an important role in shaping socially and environmentally responsible consumption (Hosta and Zabkar, 2021). Therefore, it appears to be a promising strategy to continuously inform consumers about their impact on the environment in order to bridge the intention-behavior gap.

The carbon footprint is frequently used to assess and document consumers' impact on the climate (Cadarsó et al., 2016; Zhang et al., 2015). Referring to the notion of planetary boundaries, calls to define the maximum carbon footprint per consumer become louder (Akenji et al., 2021; Rockström et al., 2009; Steffen et al., 2015). However, individual consumer emissions in Western societies currently far exceed these boundaries, with private households accounting for 60% of global GHG emissions (Ivanova et al., 2016). In line with Joerß et al. (2021), one of the key reasons for these excessive emissions is that consumers are often not aware of how much carbon dioxide they emit nor can they

* Corresponding author.

E-mail addresses: stefan.hoffmann@bwl.uni-kiel.de (S. Hoffmann), wlasarov@audencia.com (W. Lasarov), h.reimers@bwl.uni-kiel.de (H. Reimers), trabandt@bwl.uni-kiel.de (M. Trabandt).

<https://doi.org/10.1016/j.jclepro.2023.139981>

Received 16 August 2023; Received in revised form 14 November 2023; Accepted 27 November 2023

Available online 1 December 2023

0959-6526/© 2023 The Authors. Published by Elsevier Ltd. This is an open access article under the CC BY license (<http://creativecommons.org/licenses/by/4.0/>).

accurately estimate their consumption's impact on the climate. Despite the numerous preventive and informational carbon footprint-related campaigns that consumers encounter, a survey of UK supermarket shoppers revealed, for example, that only 14% of consumers were aware of their individual carbon footprint, while 89% found carbon labeling to be confusing (Gadema and Oglethorpe, 2011). Particularly for highly energy-consuming activities, recent research suggests that individuals tend to underestimate their emissions (e.g., Attari et al., 2010; Grinstein et al., 2018; Camilleri et al., 2019; van Bussel et al., 2022). Consumers therefore need assistance to become aware of what drives their carbon footprint in order to become skilled at cutting emissions. Feedback about the numeric quantity of their carbon emissions could help consumers evaluate whether their climate impact is low or high (Grinstein et al., 2018). The consumers' ability to comprehend the numerical implications of their consumption behavior is therefore frequently considered crucial for fostering sustainable consumption (Kahan et al., 2012).

Carbon footprint tracking apps (CFTAs) are technological tools that can inform and aid consumers in assessing their emissions, which, in turn, helps with making plans to adjust the consumers' consumption and reduce their emissions (Hoffmann et al., 2022). These apps enable users to save their historical consumption data, receive feedback, and add new consumption data at later periods in time, which is the basis for their long-term assessment and adjustment of their carbon footprint. Building on an established framework of psychological drivers for sustainable consumption (SHIFT; White et al., 2019) and acknowledging current trends in consumer behavior, we expect that CFTAs are powerful tools in reducing consumption-related carbon emissions, in that the apps address the information gap (Grinstein et al., 2018; Rondoni and Grasso, 2021; Gadema and Oglethorpe, 2011).

Our paper contributes to the existing literature in three essential ways. First, no study has investigated whether CFTAs can truly aid individuals in adapting their consumption habits to reduce emissions. Existing research has primarily examined factors that foster or hinder consumers' use of such applications (Hoffmann et al., 2022), or has centered on providing knowledge about consumers' carbon footprints via calculators (Collins et al., 2020). With the CFTA that we developed for this research, we are the first who can conduct a study using a real application in a controlled environment. Contrary to prior studies (Collins et al., 2020; Kim and Neff, 2009; Mulrow et al., 2019; West et al., 2016) utilizing carbon footprint calculators (CFCs), the use of a CFTA extends beyond simply quantifying consumers' carbon footprints at a single point in time. A CFTA continuously informs consumers about their carbon footprint over an extended period of time. With this study, we aim to achieve our main research goal which pertains to how individual carbon emission feedback provided by a CFTA can encourage consumers to reflect on and, ultimately, adjust their habits to diminish their emissions. Second, while there is a substantial body of research on feedback concerning the sustainable impact of consumer actions (e.g., Fischer et al., 2008; Santarius and Soland, 2018; Delmas et al., 2013; Zangheri et al., 2019; Kendel et al., 2017; Tiefenbeck et al., 2019), our specific goal is to address the lack of studies on the boundary conditions that influence the effectiveness of these feedback mechanisms. We augment the literature by introducing moderators that might influence how CFTA feedback inspires consumers to alter consumption habits and decrease associated carbon emissions. As a conceptual foundation, we build upon the SHIFT framework, a model proposed by White et al. (2019), which identifies several psychological factors intended to promote sustainable consumer behavior: social influence, habit formation, individual self, feelings and cognition, and tangibility. We explore psychographic variables rooted in sustainable consumption research, for example, emotions and green self-identity. In addition, we incorporate constructs that have proven to be pertinent in self-tracking technology contexts, such as self-efficacy, and in the nexus of technology and sustainable consumption, like the consumers' technology-as-solution belief (TSB; Joerß et al., 2021). Third, research on carbon emission feedback has not considered consumption-domain effects. We therefore explore

not only the intra-individual differences that shape the impact of feedback, but also the inter-domain differences. Our study thus covers four main domains, i.e., mobility, food, heating, and household activities, which account for nearly three-quarters of the average Western household's carbon emissions (Jones and Kammen, 2011; Tukker, 2006; Tukker and Jansen, 2006). The findings are relevant for policymakers, application designers, marketers, and consumers who are focused on reaching the goal of reduced emissions.

2. Conceptual background

We first discuss how CFTAs, by providing feedback on carbon emissions related to daily consumption, can potentially promote sustainable lifestyles. This discussion is based on existing literature on feedback effects in sustainable consumption, CFCs, and self-tracking technologies (STTs) (see Fig. 1 for an overview). Afterward, we introduce moderating variables that potentially explain differences in the effectiveness of CFTA feedback among different consumers. In Table 1 we provide an overview of exemplary studies to emphasize the motivation of our paper and to visualize the addressed research gap.

2.1. Feedback

Consumers are frequently unaware of how their daily consumption choices affect the environment and the climate. Moreover, they usually lack knowledge about how much energy an individual device or application consumes, and how much energy they save by abandoning devices or switching to more energy-efficient technologies (Fischer et al., 2008; Santarius and Soland, 2018). Arguably, carbon footprint labels help understand the carbon emissions associated with the purchase of a single product (Thøgersen and Nielsen, 2016). A wealth of research has considered the effects of carbon footprint labels (Beattie, 2012; Rondoni and Grasso, 2021). These labels are, however, product specific and primarily influence new product purchases; they are unable to provide feedback regarding general consumption (habits). In addition, consumers have insufficient knowledge and understanding of the associated carbon emissions (Grinstein et al., 2018; Rondoni and Grasso, 2021). Studies found that consumers frequently struggle to estimate their carbon emissions precisely. Particularly, consumers tend to underestimate their emissions for highly energy-consuming activities (e.g., Attari et al., 2010; Grinstein et al., 2018; Camilleri et al., 2019; van Bussel et al., 2022).

According to the literature, one of the options to encourage consumers to adopt a resource-saving consumption style is to provide feedback on the consequences of consumption, for example, in the form of individual energy consumption or reference values (Delmas et al., 2013; Zangheri et al., 2019). Extant empirical studies indicate that individual consumption feedback can potentially reduce energy consumption (Kendel et al., 2017; Tiefenbeck et al., 2019). Several review articles discuss the conditions under which feedback is effective in promoting climate-friendly consumption styles (e.g. Abrahamse et al., 2007; Buchanan et al., 2015; Delmas et al., 2013; Fischer et al., 2008). For example, Zangheri et al.'s (2019) meta-analysis on feedback about energy consumption shows that how, when, and to whom the feedback is delivered affect the feedback's resulting impact on energy consumption. Technical devices could potentially deliver the feedback in different ways, at different times, and adjusted to various target groups. Thus far, technical applications for feedback have been created for specific consumption domains, such as intelligent measuring devices in the household. Extant studies confirm that these smart meters affect energy consumption (Delmas et al., 2013; Westskog et al., 2015).

2.2. Carbon footprint calculators

CFCs are tools that provide consumers with feedback about the carbon emissions of their consumption and lifestyle. Several calculators

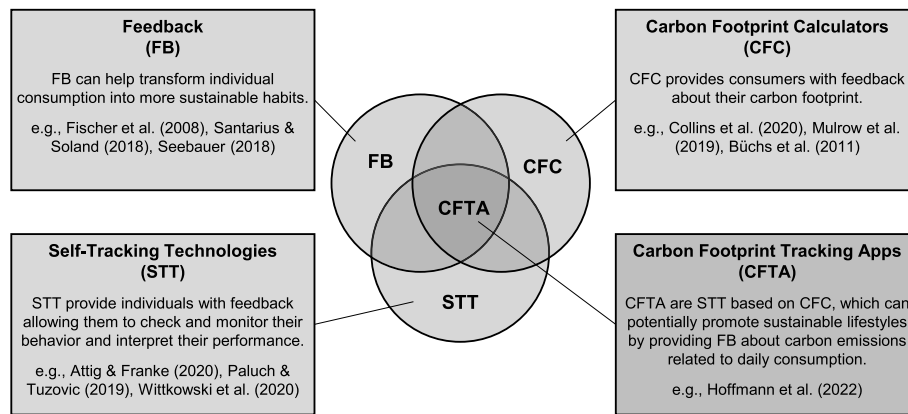


Fig. 1. Conceptual description of CFTA.

are freely available on the internet, with the calculators indicating the consumers' emissions from various sectors, such as food, transportation, energy (Collins et al., 2020; Mulrow et al., 2019). Organizations like the *WWF Footprint Calculator* (<https://footprint.wwf.org.uk>) and *myclimate.org* (<https://myclimate.org/>) launched such online tools. Previous research has demonstrated the CFC's potential to promote pro-environmental behavior, for example, in interview-based studies (Salo et al., 2019) or based on observations gained while developing a CFC (Salo et al., 2019; West et al., 2016). Another study discovered that providing consumers with details indicating how their carbon footprints compare with those of others may cause feelings of eco-pride and eco-guilt and it may foster their support for organizations that work to protect the environment (Mallett et al., 2013). According to certain studies, CFCs pique users' interest, motivate their commitment, and arm them with the information they need to make the decisions that will reduce emissions the most (Gram-Hansen and Christensen, 2012). In sum, CFCs can potentially raise individual knowledge of the impact of consumers' actions, by taking customized data into account when calculating emissions (Büchs et al., 2018). However, using a CFC to raise awareness of climate change may not necessarily result in behavioral changes (Büchs et al., 2018; Kok and Barendregt, 2021). One of the reasons for this might be that a CFC can only provide consumers with a one-time assessment of their consumption. However, consumers cannot incorporate CFCs into their everyday lives, which is what is needed to shape consumption habits in the long term.

2.3. Self-tracking technologies

STTs are tools that provide feedback to individuals, allowing them to check and monitor their behavior, and also to analyze and interpret their personal performance (Wittkowski et al., 2020). STTs can be implemented on different devices. These include smart wearables, such as wristbands or smart rings. They can also be used on smartphones as applications. STTs typically calculate performance indicators, which are then visualized in graphs and tables (Pantzar and Ruckenstein, 2015). Users increasingly keep track of their status to improve their behavior in several life domains. Examples of these domains include fitness, health, sleep, diets, financial activities, and screen time (Angosto et al., 2020; Etkin, 2016; Yan et al., 2021; Zimmermann, 2021). This endeavor of self-optimization is often even considered a lifestyle, and it is also termed the quantified-self or lifelogging. The quantified-self has emerged as a major lifestyle trend (Lupton, 2016; Paluch and Tuzovic, 2019; Swan, 2013).

The major promise of STTs is that, by monitoring consumers' actions and their resulting consequences, consumers gain more knowledge, which allows them to improve themselves and their well-being (Sharon, 2017). When consumers aim to achieve a specific goal (like losing weight or running a marathon), they are more inclined to employ STTs

(Karapanos et al., 2016). In addition, STTs aid users in understanding what they must do to achieve their objective (Karapanos et al., 2016). Some research suggests that quantification also has drawbacks. For instance, although quantification encourages users to engage in the desired behavior, it may diminish their perception of enjoyment and undermine their intrinsic motivation (Attig and Franke, 2020; Etkin, 2016).

2.4. Carbon footprint tracking apps

CFTAs are tools to provide consumers with regular feedback on their carbon emissions such that consumers can track their emissions (Hoffmann et al., 2022). CFTAs extend CFCs, which only provide one-time feedback about carbon emissions, to continuously track users' consumption and thus enable long-term behavioral changes and sustainable emission reductions. Hence, CFTAs combine the concepts of CFCs and STTs. Like STTs, CFTAs acknowledge that consumers need repeated and easily available feedback on their whole consumption to achieve a long-term change in their consumption styles. Unlike CFCs, which only provide one-time feedback about the carbon emissions, CFTAs track their users' consumption, provide repeated feedback, and thus enable long-term behavioral changes and sustainable emission reductions.

Scholars have already considered consumers' acceptance of CFTAs. Hoffmann et al. (2022) demonstrate that hedonic, social, and utilitarian benefits drive the intention to adopt a CFTA. However, the impact of the utilitarian benefits, which is operationalized as the TSB, is moderated by the extent to which consumers perceive transaction costs when using the application, namely their perception of the ease of use and their readiness to share their private data. When widely applied, such applications would have a great potential to guide consumption in the future, as more and more consumers are aware of how severe the global warming problem is and they feel personally obliged to help decelerate this development (Capstick et al., 2015). Currently, however, no study provides evidence whether or not such applications can actually help shape consumption styles and reduce carbon emissions. This paper aims to fill this void.

3. Research model and hypotheses development

3.1. Direct feedback effect

Scholars frequently emphasize that one of the most significant obstacles consumers face in pursuing more sustainable lifestyles is that they are often uninformed about the ecological impacts of their consumption habits (White et al., 2019). Even consumers who are motivated to consume sustainably often require more knowledge and understanding about different consumption options and the consequences of their choices (Gifford, 2011; Levine and Strube, 2012).

Table 1

Overview of selected relevant studies.

Study	Research type	Main findings	Sustainable consumption	Feedback	STT	CFC	CFTA	Differentiation of consumption domains	Boundary conditions
Grinstein et al. (2018)	Quantitative	There is a notable lack of precision in estimating the quantity of carbon emissions when compared to other metrics, often tending to underestimate carbon emissions. This relative deficiency in carbon numeracy may constrain the effectiveness of environmental policies and campaigns that seek to alter individual behavior.	•			•			
Tiefenbeck et al. (2019)	Quantitative	Providing real-time feedback on resource consumption during showers leads to significant energy conservation among a group of guests staying at six hotels. These participants were not financially responsible for the energy costs.	•	•					
Hoffmann et al. (2022)	Quantitative	Anticipated hedonic, social, and utilitarian benefits influence the intention to embrace carbon footprint tracking apps. The impact of utilitarian benefits is determined by consumers' perceptions of the transaction costs associated with using the app.	•				•		ease of use, willingness to provide private data
Collins et al. (2020)	Quantitative	A substantial proportion of users view calculators as valuable for acquiring knowledge or find calculators effective in inspiring action. Conversely, only a modest fraction of users believe that the calculator provides them with sufficient information to enact tangible lifestyle changes and decrease their personal carbon footprint.	•			•		•	
Salo et al. (2019)	Qualitative	Knowledge-intensive calculators are developed to facilitate a reasoned evaluation of consumers' lifestyle and activities regarding their environmental impact. These calculators offer tips and pledges to encourage sustainable behavior. Motivating individuals to use calculators, particularly on multiple occasions, is a difficult task.	•			•			
Wittkowski et al. (2020)	Quantitative	The efficacy of STTs relies on consumers' self-efficacy. In cases where consumers have low self-efficacy, the use of STTs might even hinder compliance with advice. Perceived empowerment and personalization mediate the impact of STT use on compliance with advice.			•				self-efficacy
Joerß et al. (2021)	Quantitative	The intensity of augmented reality recommendation agents (AR-RA) usage increases the amount of consumed sustainable products. Consumers are more inclined to turn to AR-RAs for sustainability-related decisions when they use digital devices more frequently, but only if they have experience in consuming sustainably and believe that technology can contribute to solving environmental problems.	•						usage of digital devices, sustainable shopping experience, technology as solution belief
Mai et al. (2015)	Quantitative	The influence of nutrition self-efficacy on behavioral intentions and eating behavior is contingent upon implicit food associations. This study highlights that merely enhancing a consumer's self-efficacy will not lead							implicit food association

(continued on next page)

Table 1 (continued)

Study	Research type	Main findings	Sustainable consumption	Feedback	STT	CFC	CFTA	Differentiation of consumption domains	Boundary conditions
Barbarossa and De Pelsmacker (2016)	Quantitative	to significant shifts towards adopting a healthier diet. Positive altruistic (care for the environmental consequences of purchasing) hold greater significance for green than for non-green consumers. Positive ego-centric (green self-identity and moral obligation) increase significantly the sustainable purchase intention for both consumer groups. Negative ego-centric (perceived personal inconvenience of purchasing eco-friendly products) exert a more pronounced influence on the purchase intentions of non-green consumers than on those of green consumers.	•						green and non-green consumers
Koenig-Lewis et al. (2014)	Quantitative	Emotions, rather than rational evaluations, play a pivotal role in driving pro-environmental purchase behavior. An individual's general environmental concern significantly influences their purchase intentions, whereas rational evaluations of benefits do not. Rational evaluations have varying effects on positive and negative emotions. Furthermore, both positive and negative emotions have significant direct effects on purchase intention.	•						
This Study	Quantitative	CFTA can curtail consumers' carbon emissions by offering feedback on the carbon consequences of consumption, with the impact fluctuating across consumption domains. Furthermore, individual traits influence the effectiveness of CFTA usage: perceived green self-efficacy enhances the feedback's effect, while a strong green self-identity mitigates it. The influence of additional boundary conditions again varies among various consumption domains.	•	•	•	•	•	•	technology as solution, green self-identity, green self-efficacy, positive and negative emotions

Notes. STT = Self tracking technologies, CFC = Carbon footprint calculators, CFTA = Carbon footprint tracking apps.

According to research on the effects of feedback on behavior, individuals whose performance was subpar during the previous period may benefit more from feedback information, because it eliminates what is known as performance uncertainty (Audia and Locke, 2003; Kaymaz, 2011). Studies have already confirmed in different contexts that giving consumers feedback on their consumption can encourage them to adopt or intensify sustainable consumption practices (e.g., Abrahamse et al., 2007; Fischer, 2008; Karjalainen, 2011; Tiefenbeck et al., 2016). Fischer (2008) highlighted in her research review on home electricity consumption that households who received feedback about their excessive energy usage were more motivated to minimize their use. Past research has shown the effectiveness of feedback across various lifestyle domains (such as health, fitness, and sustainability) and technological aspects (including self-tracking tools and CFCs). Studies demonstrated that several tools and technologies, such as self-tracking tools, CFCs, and website feedback (Abrahamse et al., 2007; Kendel et al., 2017; West et al., 2016), as well as smart meters and in-home displays (Buchanan et al., 2015; Tiefenbeck et al., 2019), can effectively influence user behavior toward desirable outcomes. In addition, the positive impacts of feedback have been substantiated across various domains, including but not limited to fitness (Angosto et al., 2020) and health (Yan et al., 2021; Etkin, 2016; Zimmermann, 2021). Extending these findings to the

domain of CFTAs, we presume that the feedback provided by a CFTA stimulates consumers to reevaluate and reshape their consumption and thus to reduce carbon emissions. Arguably, consumers with high emissions have more opportunities to reduce carbon emissions. The higher the emissions that are communicated back to consumers, the more motivated they should be to change their consumption patterns.

H1. The higher the level of carbon emissions that consumers receive as CFTA feedback, the higher is their planned carbon emission decrease.

Consumers also use feedback as a learning tool to identify which activities emit the most carbon emissions, and adjust their behavior accordingly (McClelland and Cook, 1979). While feedback on high carbon emissions generally encourages consumption reduction, the strength of the feedback effects may differ between domains, for several reasons. First, for each consumer, the relative share of each domain's emissions might be different, and consequently there is a strong variety of emissions in the different domains across different consumers (Collins et al., 2020). Imagine, for example, that consumer A is highly involved in reducing emissions from household activities (e.g., switching off machines when not used) and food (e.g., adopting a vegan diet), but rents an old house with an outdated heating system and with poor thermal insulation, and flies to far-off vacation destinations. As a result,

consumer A will have comparatively low emissions in the domains household activities and food, but relatively high emissions in heating and mobility. Consumer B might have the opposite pattern, as this consumer is keen on purchasing and using new technologies and eating meat, but lives in a modern, efficient house and rides an electric bike. While both consumers may have roughly the same level of overall carbon emissions, their domain-specific feedback might differ largely. Hence, consumers A and B might feel guilty and obligated to save emissions in different domains (Cameron et al., 1998), and, in fact, the potential to save emissions also varies across consumption domains.

Second, domain-specific boundary conditions cause significant disparities between consumption domains. The relevant boundary conditions include variations in the feasibility of consumption changes (e.g., consumers can easily change their consumption in one domain but not in the other), different consumption patterns (e.g., more hedonic or functionally driven), external boundary constraints (e.g., pricing, alternatives), and motivating considerations (e.g., health-related considerations in the reduction of consumption in a specific domain) (McCalley and Midden, 2002). For example, some consumers may find it more challenging to reduce the use of their personal car due to a lack of alternatives (e.g., because of limited access to public transportation), whereas they might find it easier to lower their meat consumption, which comes with additional health benefits. Moreover, we assume that consumers can estimate their carbon emissions in some domains more adequately than in other domains. The impact of carbon emission feedback will be higher if consumers are less capable of estimating their emissions accurately, since in this case carbon emission feedback helps them eliminate performance uncertainty (Grinstein et al., 2018; Collins et al., 2020).

Third, carbon emissions in different domains, such as food, mobility, heating, and household activities, strongly depend on the consumers' habits in these domains. According to White et al.'s (2019) SHIFT framework, habits are persistent, as consumers execute them relatively automatically over time. Interventions that break repetition are needed to stimulate discontinuity and habit change. Information, prompts, and feedback can help break habits. We assume that the feedback needs to be domain specific to break the habit in exactly that domain. All in all, we assume that consumers are particularly motivated to reduce consumption in those domains where their emissions are at a high level.

H2. The strength of the effect of the carbon footprint feedback can vary between different domains. The higher the emission feedback in a particular domain is, the larger is the planned carbon emission decrease in this domain.

3.2. Moderated feedback effects

The carbon footprint feedback will not exert the same effect on every consumer. It is reasonable to assume that personal characteristics moderate how consumers process the feedback information and how this influences their planned consumption. With reference to the SHIFT framework (White et al., 2019) and other related literature (e.g., Hoffmann et al., 2022), we consider the TSB, green self-efficacy, green self-identity, as well as positive and negative emotions crucial. In the following, we discuss how these potential moderators might affect how people respond to CFTA feedback. Notably, we anticipate that the importance of these potential moderators will vary across domains.

3.2.1. Technology as solution belief

The TSB is defined as "the extent to which consumers are generally open to using technical innovations to resolve sustainability issues" (Joerß et al., 2021, p. 514). This construct is based on the observation that digital tools can provide consumers with context-specific, personalized, fast, and easy access to real-time information. Despite this advantage over more traditional ways of information, some consumers refuse the idea to use digital tools to increase sustainability. They may

believe that sufficiency and more traditional, pre-industrial lifestyles are the best response to environmental problems (McGouran and Prothero, 2016). To measure this interpersonal variation, the TSB construct therefore grasps the extent to which consumers agree that technology may be useful in resolving environmental issues (Joerß et al., 2021).

Joerß et al. (2021) used the TSB construct to explain when consumers use augmented reality tools that recommend more sustainable product options at the point of sale. Hoffmann et al. (2022) applied the TSB to predict CFTA adoption. Interestingly, both studies show that the TSB construct mainly serves as a moderator variable. According to the study of Joerß et al. (2021), the TSB interacts with factors such as digital device usage habits to predict whether or not consumers use augmented reality-enabled recommendation systems. Hoffmann et al. (2022) have shown that the TSB interacts with the perceived ease of use and the perceived vulnerability to predict the intention to adopt a CFTA. Accordingly, we assume that the TSB also mainly plays a moderating role with regard to the way in which CFTA feedback affects consumption changes. We anticipate that users who have a high belief in technology will be more inclined to rely on the information and feedback these tools provide, which will influence their future consumption patterns. On the other hand, the CFTA feedback will be less effective for consumers with a poor TSB.

H3. The stronger the consumers' TSB is, the stronger is the carbon footprint feedback's effect on carbon footprint decreases associated with planned consumption changes.

3.2.2. Green self-efficacy

Self-efficacy is defined as "the belief in one's competence to cope with a broad range of stressful or challenging demands" (Luszczynska et al., 2005). According to social cognitive theory, individuals who have a high level of self-efficacy are more inclined to engage in a particular action (Bandura, 2012). The predictive power of self-efficacy is particularly strong when conceptualized as a domain-specific instead of a general construct. This has been demonstrated, for example, with regard to health and nutrition (Renner et al., 2000), and also with regard to the use of services (McKee et al., 2006).

Extant studies reveal that domain-specific self-efficacy functions as a moderator variable that amplifies the effects of other predictors (Mai et al., 2015). In their study regarding the health sector, Wittkowski et al. (2020) considered how the use of STTs and self-efficacy interact in the prediction of advice compliance. As expected, high levels of self-efficacy amplified the likelihood that people follow the advice, while low levels may even have the opposite effect. Building on these arguments, and related to a change in consumption habits being a challenging demand (White et al., 2019), we assume that the carbon footprint feedback's effect on the carbon footprint change will be particularly strong for those consumers with a high level of domain-specific self-efficacy, which we label green self-efficacy.

H4. The stronger the consumers' green self-efficacy is, the stronger is the carbon footprint feedback's effect on carbon footprint decreases associated with planned consumption changes.

3.2.3. Green self-identity

Clayton (2003) described identities as ways to form a self-concept and organize information about the self. We conceptualize the construct of green self-identity in the field of consumption as a domain-specific construct. We build on the constructs of green self-identity (Lalot et al., 2019) or, synonymously, environmental self-identity (Dermoddy et al., 2018). Environmental self-identity is defined as "the extent to which one sees oneself as a type of person whose actions are environmentally friendly" (van der Werff et al., 2013, p. 1258). Environmental self-identity is highly correlated with pro-environmental behavior (e.g. Walton and Jones, 2018).

Prior research has shown that antecedents of sustainable behavior vary between consumers, i.e., between those who identify themselves as

green and those who do not (Barbarossa and De Pelsmacker, 2016). We assume that green self-identity largely interacts with CFTA feedback. Vallacher and Wegner (1989) classified consumers into two categories: low-level agents and high-level agents. Low-level agents concentrate on individual decisions and behaviors, while high-level agents take into account contextual factors, evaluating their consumption in terms of broader and more abstract impacts. Consumers who identify strongly as green (high-level agents) are expected to have very detailed knowledge and opinions about how consumption affects the environment and climate at large. They will be especially skilled at interpreting CFTA information and especially driven to take actions that will lessen their carbon footprint (Collins et al., 2020). This argument is in line with research on the effects of feedback, which contends that for passive and uninformed individuals, feedback can reduce performance ambiguity, which can stimulate their efforts to improve their performance (Bennett et al., 1990). As a result, we anticipate that having a weak green self-identity (low-level agents) will amplify the feedback's influence, since it allows consumers with weak green self-identity to connect the consequences of specific actions to their aggregated impact on the environment.

H5. The weaker the consumers' green self-identity is, the stronger is the carbon footprint feedback's effect on carbon footprint decreases associated with planned consumption changes.

3.2.4. Emotions

White et al.'s (2019) SHIFT framework outlines that positive and negative emotions can affect environmental behavior. Hence, in addition to the rather cognitive elements proposed in H3–H5, we believe that emotional processes can also enhance the carbon footprint feedback's effect on carbon footprint change. Previous studies indicated that emotions influence the people's capacity to govern personal decisions in favor of long-term goals (Baumeister, 2002; Haidt, 2003; Tangney et al., 2007). Particularly, self-conscious emotions, i.e., those that are affected by how individuals see themselves and how they think others perceive them, have been identified as major supporters of sustainable consumption behaviors (Carrus et al., 2008; Pelozo et al., 2013; Wang and Wu, 2016). Scholars revealed the favorable impacts of negative emotions, such as guilt, fear, and rage (Kaiser, 2006; van Zomeren et al., 2010). Positive emotions, such as pride, security, and happiness (Li et al., 2019; Onwezen et al., 2014), are emotions related to self-esteem and achievement and therefore also motivate to engage in future sustainable consumption (Gregory-Smith et al., 2013; Higgins et al., 2001; Williams and DeSteno, 2008).

Both positive and negative emotions can boost consumers' willingness to consume sustainably in general (Carrus et al., 2008; Koenig-Lewis et al., 2014) and also when these emotions are used as feedback on consumers' carbon footprint (Mallett et al., 2013). This effect can be attributed to people's habit of pursuing positive emotions and avoiding bad emotions (Frijda, 2007). Building on this rationale, we suggest that both positive and negative emotions may amplify the carbon emission feedback's impact on planned consumption intentions. Consumers who have more positive emotions in reflecting on their sustainable purchases are more likely to respond strongly to the carbon emission feedback, since they predict that being more sustainable will elicit stronger desirable emotions, such as joy, pride, etc. On the other hand, customers who feel strongly negative emotions while considering their sustainable behaviors will strive to avoid more negative emotions and will therefore also respond more strongly.

H6. The stronger the consumers' positive emotions are, the stronger is the carbon footprint feedback's effect on carbon footprint decreases associated with planned consumption changes.

H7. The stronger the consumers' negative emotions are, the stronger is the carbon footprint feedback's effect on carbon footprint decreases associated with planned consumption changes.

In sum, we propose the conceptual model depicted in Fig. 2, which guides our research.

4. Design

4.1. Procedure

We developed the CFTA eco2log that was created primarily for research purposes, and that was validated in numerous pretests. The application allows users to calculate the carbon footprint of their consumption as well as the effects of consumption changes on the individual carbon footprint. The carbon footprint expresses the amount of carbon dioxide emissions that are caused by consumption (Wiedmann and Minx, 2008). The largest share of demand-side GHG emissions stem from the demand for energy, mobility, food, and housing (Nielsen et al., 2020; Stern and Dietz, 2020), and it is estimated that the categories of transportation, housing, and food account for nearly three-quarters of the average Western household's carbon emissions (Jones and Kammen, 2011; Tukker, 2006; Tukker and Jansen, 2006). Consequently, the application focuses on the domains of mobility, food, heating, and household activities.

The application displays statistics, which illustrate the carbon emissions of a person's overall consumption and subdivided into consumption domains (Appendix Figure A1, left-hand side, for screenshots of the application). Users can regularly specify whether and how much their consumption has changed in a particular consumption domain, and the application provides them with feedback about the changes' impact on their carbon footprint (Appendix Figure A1, right-hand side). The ethical committee of our university approved this application as a tool for research.

The study consisted of several steps. In the first step, we asked the participants to download the application, to install it on their smartphone or tablet computer, and to log in. The participants were asked to use a code nickname instead of their real name, which they had to use in the questionnaire, also to enable us to combine the data from the application and the questionnaire. The participants then entered their socio-demographic details (year of birth, gender, household size, etc.). They also responded to a few scales (e.g., green self-identity, price consciousness, etc.), which are recorded on a regular basis when using the application for the first time.¹

In the second step, the participants switched to an online questionnaire. After entering their nickname, they responded to a series of scales, including green self-identity and the subjective self-estimation, i.e., whether they produce more or less carbon emissions than other people in Germany. Note that this omnibus study also includes a number of other scales.² We only use and report the relevant scales here.

The third step required participants to return to the application and enter their past consumption structured along the four domains of mobility, food, heating, and household activities. They had to answer approximately 150 questions. Table A1 in the appendix provides an overview of exemplary questions that the CFTA includes to capture participants' consumption in the four domains. However, the

¹ Note that we measured some scales in the app as a standard procedure for all app users. We replicated the measurement of the relevant scales in our questionnaire, which was only administered to the study participants. The wording of the items of the scales is identical if it was used in both the app and the questionnaire. The wording of items of scales that we used for the analysis are documented in Appendix Table A2.

² Across the multiple steps, the participants answered scales, such as moral obligation, subjective knowledge, seriousness, perceived consumer efficacy, perceived responsibility, ideal consumption, action efficacy, counter arguments (small agent), app credibility, self-improvement motivation, self-accountability, perceived ease of use, perceived usefulness, perceived vulnerability, hedonic benefit, utilitarian benefit.

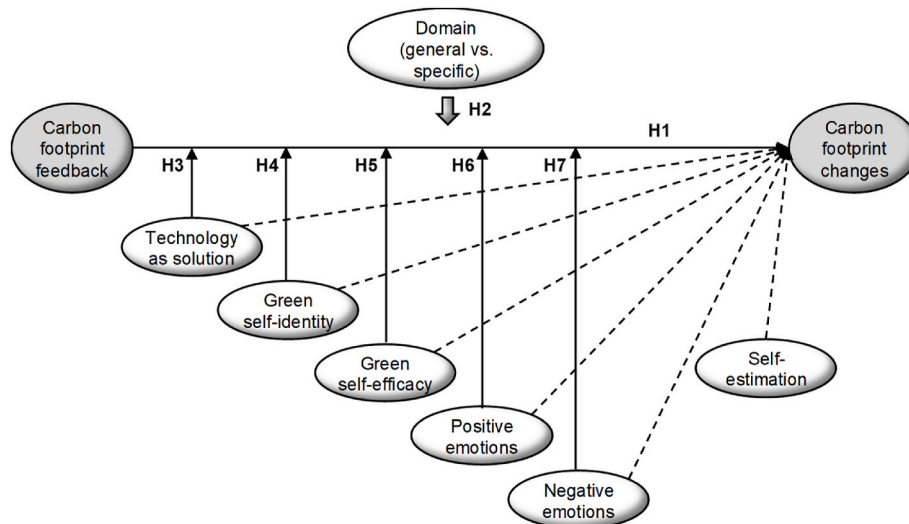


Fig. 2. Conceptual model.

participants were not required to respond to each question. We included default values for the German population if the participants did not know the answers to some questions (such as the type of heating they used). After they had entered all their data, the application calculated the users' carbon emissions and gave them feedback on both the overall emissions as well as the four consumption domains of mobility, food, heating, and household activities. The participants could click on these domains and obtain even more detailed information (e.g., the emissions caused by flight traveling).

The participants returned to the online questionnaire in the fourth step. They entered the total emissions as well as the emissions caused in each of the four domains in the questionnaire. Following that, the participants responded to several scales, including green self-efficacy and positive and negative emotions.

In the fifth step, the participants were asked to enter how they would modify their consumption in the future. They then used the application to exactly document the planned consumption changes. Thereby, they could select a particular domain (such as mobility) and a subdomain (such as driving to work) and edit the entries they made with the application during the first round. Afterward, they once again received feedback about their carbon emissions (overall, and in the four domains).

Finally, the respondents again went back to the questionnaire, entered their emissions, and answered more questions of the omnibus survey. From this round, we only used the TSB scale in this study. The participants were incentivized with EUR 20 for taking part. On average, it took the participants 84 min to install the app, log in, enter their consumption data, read the feedback, and answer the first questionnaire (step 1–3). Then they spent 12 min on average to modify data in the app and answer questions in step four. It took another 12 min to fill out the final questionnaire. Given this extensive procedure, we added three attention checks in the questionnaires (one in each sub-questionnaire). Participants were asked to check a specific box of the answering scale. Participants who failed more than once were excluded from the data set. While the app was freely available and could be used by multiple users, the respondents could enter our study only once. We only took data from app users who were connected to the questionnaires via a nickname. Only these participants received the incentive. Since participants had to personally come to the laboratory to receive the incentive and identify themselves as participants, we would have recognized if someone appeared twice. Moreover, the motivation to complete the whole procedure of the app and the questionnaire a second time without an

incentive is very low, given that it took participants almost 2 h to go through the whole process.

4.2. Calculation of carbon footprint

To calculate each user's individual carbon footprint, the application primarily uses the extensive list of formulae and reference values that [Kleinhüeckelkotten and Neitzke \(2016\)](#) provided for the German population. We refined these formulae whenever necessary and performed numerous validation checks of the calculations. When first using the application, users are guided through a questionnaire to insert which products and services they use in the four categories. Users must enter numerous details in this questionnaire (e.g., type and construction year of their heating). Certain users might simply not know or might not want to disclose particular details. To prevent these users from dropping out, and to be able to provide feedback on overall carbon emissions, the application used predefined default values for all skipped items. The default values replaced missing data and helped calculate values that fit to the average of the German population. These default values are based on research concerning average consumer behavior or on documented defaults ([Kleinhüeckelkotten and Neitzke, 2016](#)).

We applied the following method to measure whether the CFTA can actually initiate a change in carbon emissions. We calculated the difference between the feedback on the carbon emissions and the feedback on the intended consumption change. Using the CFTA's feedback on the carbon emissions of planned consumption has a number of benefits over using subjective assessments: Compared to self-reported planned consumption, the numbers calculated by the application are not just a subjective statement of behavioral change. The users realize how many emissions they can save in certain subdomains when they modify their behavior in this domain.

We used Equation (1) to calculate the emission changes caused by the intended consumption changes. The formula is applied for the overall consumption and for the four domains of mobility, food, heating, and household activities:

Equation (1). Calculation of emission change between current and intended consumption

$$FE \text{ change}_{\text{domain}} = FE \text{ current consumption}_{\text{domain}} - FE \text{ intended consumption}_{\text{domain}} \quad (1)$$

Notes. FE: Feedback emission.

As a robustness check, we reran the basic analyses with the relative different (in %) calculated as follows (Equation (2)).

Equation (2). Calculation of relative emission change between current and intended consumption

$$\text{Relative FE change}_{\text{domain}} = \frac{\text{FE}_{\text{current consumption domain}} - \text{FE}_{\text{intended consumption domain}}}{\text{FE}_{\text{current consumption domain}}} \quad (2)$$

Notes. FE: Feedback emission.

4.3. Measurement

To measure the participants' self-estimation of their carbon emission, we asked them to estimate on seven-point scales ranging from very low (1) to very high (7) if their carbon emissions are high or low. We asked for the overall self-estimations, and also for the self-estimations in the four consumption domains (mean (M): $M_{\text{overall}} = 3.94$, standard deviation (SD): $SD = 1.11$; $M_{\text{mobility}} = 3.41$, $SD = 1.73$; $M_{\text{food}} = 3.71$, $SD = 1.41$; $M_{\text{heating}} = 3.85$, $SD = 1.44$; $M_{\text{household}} = 3.56$, $SD = 1.18$).

All of the following indicators are measured on seven-point rating scales. The wording and the factor loadings are documented in the Appendix (Table A2). We operationalized the TSB with three items adopted from Joerß et al. (2021) (Cronbach's (1951) alpha: $\alpha = 0.826$, $M = 5.58$, $SD = 1.05$). We measured green self-identity with three items ($\alpha = 0.847$, $M = 4.97$, $SD = 1.08$), which we built on bases of Sproles and Kendall (1986), Haws et al. (2014), and Walton and Jones (2018). To measure green self-efficacy ($\alpha = 0.861$, $M = 5.06$, $SD = 1.15$), we adapted four items from Mai et al. (2015). We took five items from Tangney et al. (1996) to measure negative emotions ($\alpha = 0.878$, $M = 3.57$, $SD = 1.22$) and we took four items, also from Tangney et al. (1996), to measure positive emotions ($\alpha = 0.794$, $M = 3.89$, $SD = 1.02$).

Cronbach's alpha confirms the internal consistency of all multi-item scales. We ran confirmatory factor analysis (Harrington, 2009) with AMOS 28.0 (analysis of moment structures; Arbuckle, 2019) with all multi-item constructs. The analysis shows a good model fit ($\chi^2_{(142)} = 326.51$, $\chi^2/\text{d.f.} = 2.30$; comparative fit index: CFI = 0.92; root mean square error of approximation: RMSEA = 0.08; Baumgartner and Homburg, 1996). The analysis confirms discriminant validity (Fornell and Larcker, 1981), because the average variance extracted of each construct is higher than the maximum of the squared correlations of the construct with all latent variables (see Appendix, Table A2).

4.4. Sample

We collected data of 241 students at a university in a mid-size German city in winter 2021/2022. After data cleansing, the final sample consisted of 216 participants. We excluded participants with incomplete data, those who failed attention checks more than once, those who indicated very extreme values when they entered their carbon emission feedback in the questionnaire, and those who did not allow us to use their data for scientific purposes. Of the participants who indicated their gender, 58.9% are female and 41.1% are male (19 missing). The participants' mean age is 24.0 years (ranging from 18 to 28, $SD = 3.3$, 15 missing). We applied multiple measures to ensure that the respondents participated only once.

5. Results

5.1. Effects of feedback on consumption changes

Ordinary least squares (OLS) regression (e.g., Hair et al., 2018) demonstrates that the level of overall feedback is actually related to the carbon emission reduction due to planned consumption modifications ($\beta = 0.532$, $t(195) = 8.778$, $p < .001$). This finding confirms H1. A robustness check with the relative difference as dependent variable also

supports this finding ($\beta = 0.206$, $t(195) = 2.947$, $p < .01$).

Supporting H2, further analyses show that the stronger the feedback in a domain is, the stronger the planned changes in this domain are (see Table 2, grey shaded cells). We ran this analysis with the absolute differences (Equation (1)) and found strong effects. We then reran this analysis with the relative differences (in percent, Equation (2)). As documented in Table A3 in the appendix, the pattern of results is stable, although the effects are less strong and the effects for heating and mobility are now marginally significant. Independently of the calculation of the difference, we can conclude that the CFTA effects are mainly domain specific. The feedback about the carbon emissions in a certain domain drives consumers to change their behavior in this specific domain, whereas there are almost no cross-effects from the feedback in one domain to the changes in another domain.

To determine the extent to which CFTA feedback stimulates consumption changes directly, resulting in changes in carbon emissions, we used the difference between carbon emissions reported in the CFTA feedback after the initial entering of the current consumption and the CFTA feedback of carbon emissions after the participants entered their future consumption plans. As documented in Table 3, after using the application, the carbon emissions associated with the planned consumption decreased overall and in all four domains (see Fig. 3 for the visualization of the reduction).

The results show that confronting consumers with their carbon footprint actually stimulates them to plan for the modification of their consumption style in such a manner that emissions are reduced. Remarkably, the induced consumption reduction is largely domain specific. While we find a statistically significant overall reduction of 22.5% ($t(203) = 6.316$, $p < .001$), the intended reduction is higher for the domains of household (34.7%, $t(203) = 7.028$, $p < .001$) and heating (26.9%, $t(203) = 5.310$, $p < .001$), while it is lower for food (16.4%, $t(203) = 9.673$, $p < .001$). For mobility, the intended reduction is very low and only marginally significant (12.0%, $t(203) = 1.682$, $p = .094$).

We ran an analysis of variance (ANOVA; e.g., Hair et al., 2018) with current and planned consumption as within factors and carbon emissions in the four consumption domains as between factors, resulting in a 2 (within subjects: current, planned consumption) \times 4 (between subjects: heating, food, household activities, mobility) design. The results demonstrate that the within-subjects factor has a significant influence ($F(1, 203) = 39.898$, $p < .001$), indicating that the difference in carbon emissions between consumers' present and planned consumption varies. We also discovered a significant influence of the between-subjects factor ($F(3, 203) = 34.148$, $p < .001$), indicating that carbon emissions differ across consumption domains. Finally, the analysis reveals a factor 1 \times factor 2 interaction effect ($F(3, 203) = 5.656$, $p < .001$), demonstrating that the difference in emissions between current and planned consumption varies across consumption domains.

5.2. Self-estimation vs. feedback of actual carbon footprint

Hypothesis H2 bases on the assumption that consumers are often unaware of the consumption domains in which they intensively produce carbon emissions and the domains in which their carbon footprint is rather small. Therefore, we investigated how well consumers could estimate their carbon emissions across different domains, by testing the correlations between self-estimation and CFTA feedback. As shown in Table 4, the self-estimations are, in most cases, correlated across different domains. The CFTA feedback is also correlated across different domains. The overall CFTA feedback is also correlated with the overall self-estimation. However, the self-estimation within a particular domain and the actual feedback in that domain are not correlated. Accordingly, it seems that consumers are not good at estimating their emissions in specific domains.

Table 2
Feedback Effects (absolute differences).

Feedback	Heating			Food			Household			Mobility		
	B	T	p	β	T	p	β	T	p	β	T	p
- Heating	.31***	4.52	.00	-.01	-.18	.86	-.02	-.45	.65	.02	.29	.77
- Food	-.05	-.73	.47	.39***	5.93	.00	-.10*	-2.18	.03	-.13*	-2.35	.02
- Household	.00	-.05	.96	.17*	2.52	.01	.75***	15.80	.00	-.04	-.74	.46
- Mobility	.14*	2.10	.04	-.10	-1.52	.13	.07	1.56	.12	.61***	10.67	.00
F	6.974***			11.949***			68.045***			30.892***		
R ²	.123			.194			.578			.383		
R ² adj	.105			.177			.569			.371		

Notes. OLS regression. DV: carbon footprint difference: feedback consumption - feedback intention (absolute difference, Equation 1). Level of significance: + $p < .10$, * $p < .05$, ** $p < .01$, *** $p < .001$.

Table 3
Comparison of feedback of current and planned consumption.

	Carbon Emission		Correlation		Difference		T-Test	
	Current consumption	Planned consumption	r	p	absolute	Relative (in %)	T (df = 203)	p
Overall	4427	3430	.709***	.000	997	22.50%	6.316***	.000
Heating	1621	1185	.790***	.000	436	26.90%	5.310***	.000
Food	452	378	.679***	.000	74	16.40%	9.673***	.000
Household	902	589	.511***	.000	313	34.70%	7.028***	.000
Mobility	1451	1277	.679***	.000	174	12.00%	1.682+	.094

Notes. r = Pearson product-moment correlation. T-test for paired variables. Level of significance: + $p < .10$, * $p < .05$, ** $p < .01$, *** $p < .001$.

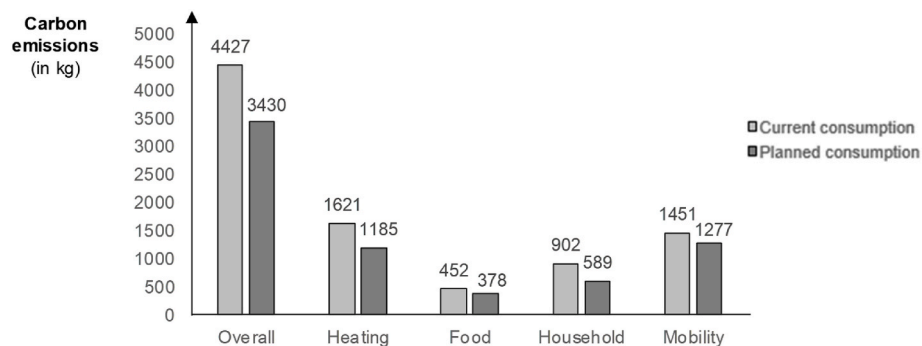


Fig. 3. Comparison of Feedback: Current Consumption vs. Planned Consumption.

Table 4
Self-estimation vs. CFTA Feedback.

	Overall	Heating	Food	Household	Mobility	Overall	Heating	Food	Household	Mobility
Self-estimation										
Overall										
Heating	.394**									
Food	.460**	.045								
Household	.422**	.378**	.161*							
Mobility	.593**	.063	.247**	.193**						
CFTA feedback										
Overall	.151*	-.022	.105	.084	.250**					
Heating	.007	.031	.023	.062	.062	.707**				
Food	.187**	-.044	.020	.040	.309**	.723**	.112			
Household	.105	-.016	.193**	.097	.095	.458**	.171*	.138*		
Mobility	.023	-.107	.390**	-.020	-.062	.214**	.195**	-.043	.169*	

Notes. Pearson product-moment correlation. Level of significance: * $p < .05$, ** $p < .01$.

Table 5
Regression of the carbon footprint difference between current and planned consumption with interaction.

	Overall			Heating			Food			Household			Mobility		
	β	T	p	β	T	p	β	T	p	β	T	p	β	T	p
Feedback															
overall domain	.42	.80	.43	.06	.74	.46	-.03	-.47	.64	.12	**	2.54	-.05	-.59	.56
Self-estimation	.00	.04	.96	-.199	-.247	.01	.94	2.35	.02	.50		1.14	.61	1.26	.21
overall domain				-.07	.62	.53	-.01	-.11	.91	-.04		-.74	.07	.95	.34
					-.1.15	.25	.03	.30	.76	.03		.59	-.13	-.1.85	.07
Technology as solution	-.05	-.54	.59	-.21	-.2.27	.02	.17	1.37	.17	-.10		-.1.44	.07	.96	.34
Green self-efficacy	-.17	-.1.52	.13	-.18	-.1.70	.09	-.21	-.1.47	.14	-.19	*	-.2.36	-.09	-.1.06	.29
Green self-identity	.48	4.09	.00	.39	3.61	.00	.18	1.08	.28	.41	***	5.01	.09	1.10	.27
Positive emotions	.23	1.85	.07	.12	1.04	.30	.06	.46	.65	.05		.66	.51	.87	.39
Negative emotions	-.21	-.1.72	.09	-.33	-.3.08	.00	.09	.60	.55	-.02		-.21	-.03	-.30	.76
Feedback (domain)															
× technology as solution	.50	1.28	.20	2.23	3.64	.00	-.90	-.2.21	.03	.42		1.39	-.46	-.1.23	.22
× green self-efficacy	1.09	3.58	.00	1.12	3.25	.00	.97	3.83	.00	1.02	***	3.44	1.23	2.95	.00
× green self-identity	-.1.28	-.4.28	.00	-.2.01	-.5.19	.00	-.33	-.1.20	.23	-.93	***	-.4.53	-.10	-.30	.77
× positive emotions	.30	1.14	.25	1.04	3.51	.00	-.27	-.1.02	.31	.10		.40	-.34	-.1.11	.27
× negative emotions	-.45	-.1.48	.14	.00	-.01	.99	.05	.23	.81	-.31		-.1.51	-.27	-.98	.33

Notes. OLS regression. DV: carbon footprint difference: feedback consumption - feedback intention (absolute difference, equation (1)). Level of significance: + $p < .10$, * $p < .05$, ** $p < .01$, *** $p < .001$. All variables are z-standardized before calculating the interaction terms.

5.3. Moderated feedback effect

To assess the suggested moderating effects (hypotheses H3–H7), we employed OLS regressions. We z-standardized all indicators before calculating the interaction terms. The findings are summarized in Table 5. We identified strong interaction effects for the TSB in the heating and food consumption domains. Interestingly, the heating interaction effect is positive, but the food consumption interaction impact is negative. Interactions with self-efficacy are significant across all examined consumption domains and for the overall effect. We also found a negative green self-identity interaction effect for overall consumption, and also in the heating and household domains. Positive emotions have a significant moderating influence, but only in the heating domain. Negative emotions have no moderating influence in any domain.

The statistically significant interaction terms for the overall consumption are displayed in Fig. 4. The graphs and the conditional effects (-1SD, M, +1SD) of the spotlight analysis (Hayes, 2017) show that the carbon emission feedback never has a negative influence on emission changes due to changed consumption. For green self-efficacy, the influence grows stronger with higher levels of the moderator, with statistically significant effects on all three levels of the spotlight analysis. In contrast, for green self-identity, the influence becomes weaker with higher levels of the moderator. While the effects are statistically significant for the levels -1SD and M of the moderator, it is only marginally significant for +1SD of the moderator.

6. Discussion

This study is the first to analyze whether and how CFTAs can stimulate consumption changes. While existing literature has only considered the drivers of the intention to adopt CFTAs (Hoffmann et al., 2022), our work demonstrates that a CFTA can be a useful tool for helping consumers change their consumption habits in order to reduce their carbon footprint. Previous research has indicated that feedback can indeed stimulate consumption changes that lead to a reduction of carbon emissions (Tiefenbeck et al., 2019). Our findings are in line with these results and show that feedback can potentially lead to an averaged decrease of 23% consumption-related emissions. Notably, and also corroborating previous research (Fischer, 2008; McClelland and Cook, 1979), our study shows that the higher the feedback in a specific consumption domain is, the more consumers intended to alter their consumption in this domain. Hence, we conclude that the CFTA effect is domain specific. By decomposing total consumption into four main consumption domains, we show that these intentions to change consumption vary significantly across different domains, ranging from a 12% reduction in mobility to a 35% reduction in household activities. Looking at different domains enabled us, in contrast to previous research, to delve deeper into cross-domain effects. However, our results provide no indication for any cross-domain effects. Hence, our study indicates that confronting consumers with high levels of carbon emissions, for example, in the domain food, will not stimulate more or less emissions in another domain, such as mobility.

Furthermore, our study shows that the CFTA effects are moderated. Including different moderator variables in our model, such as the TSB, green self-efficacy, green self-identity, as well as positive and negative emotions, improves the prediction of planned carbon footprint changes. In our study, the moderators' impacts vary across the consumption domains. Our findings indicate that green self-efficacy is the most relevant moderator, which has a reinforcing effect in each domain.

Finally, our research corroborates previous findings that suggest that consumers find it difficult to estimate their carbon emissions (Grinstein et al., 2018). We add to this notion by demonstrating that the validity of consumer estimations tends to be good for the overall estimation, but the self-estimation and the actual feedback within a particular domain are not correlated. In the following sections we interpret our results with

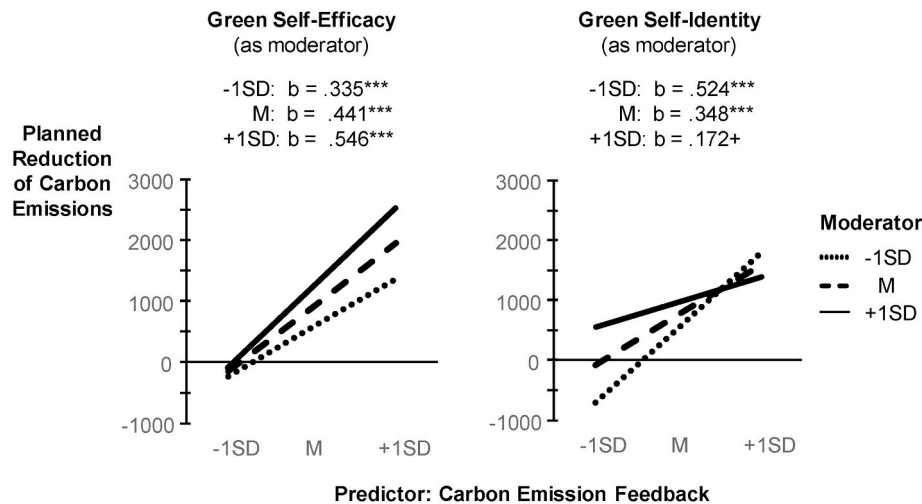


Fig. 4. Interaction Effects (Overall Consumption).

Notes. DV = difference in feedback between current and planned consumption (Equation (1)). Interaction effects calculated with SPSS add-on PROCESS 4.0 (model 1, CI = 95%, bootstrapping with 5000 samples; Hayes, 2017), variables centralized; in each calculation all other moderators and self-estimation are included as covariates. Level of significance: + $p < .10$, * $p < .05$, ** $p < .01$, *** $p < .001$.

regard to their theoretical, practical, and research implications, and we also discuss the limitations of our work.

6.1. Theoretical contributions

Our paper presents several unique contributions to the existing literature. First, several studies have already investigated different means, such as digital nudging (e.g. Berger et al., 2022), social norms (Pristl et al., 2021), a sustainable grocery shopping environment (Munro et al., 2023), and relational proximity (Weber et al., 2021), to foster sustainable consumption. Nevertheless, the attitude-behavior gap (e.g. ElHaffar et al., 2020; Mai et al., 2021) still remains a significant hurdle for consumers to behave sustainably. We examine a digital tool that can potentially address all factors that the SHIFT framework (White et al., 2019) identifies as crucial to close the gap. We extend the literature by showing how digital tools like CFTAs might function as a means to tackle the most relevant consumption domains for facilitating climate-friendly behavior. While prior research has investigated the motivation behind using CFTAs (Hoffmann et al., 2022) or emphasized educating consumers about their carbon footprints through calculators (Collins et al., 2020), our paper is the first to use a CFTA to empirically examine the effectiveness of feedback in promoting climate-friendly consumer behaviors.

Second, this study indicates that CFTAs have the potential to address all five psychological factors that White et al. (2019) theoretically suggest to foster sustainable consumption: social influence, habit formation, individual self, feelings and cognition, and tangibility. By doing so, we provide an extension of the SHIFT framework to the digital world. By including green self-identity, we analyze the social influence on the capability of CFTAs to foster sustainable consumption. Our work builds upon research surrounding feedback in sustainable consumption, making use of various studies (e.g., Fischer et al., 2008; Santarius and Soland, 2018; Delmas et al., 2013; Zangheri et al., 2019; Kendel et al., 2017; Tiefenbeck et al., 2019). Thereby, we follow White et al. (2019) to successfully change habits through feedback. While green self-efficacy tackles the individual self as an important driver of sustainable behavior, we also include positive and negative emotions as contingency variables to evaluate the role of feelings and cognition (White et al., 2019) related to the power of CFTAs. We empirically assess the moderating impact of these variables on the potency of feedback to encourage consumers to modify their consumption behaviors. Third, by investigating consumption-domain effects, we have also charted new

territory in literature by pinpointing both intra-domain and cross-domain effects.

Lastly, in contrast to findings in the existing literature that focuses on non-digital means to foster sustainable consumption, green self-identity interacts negatively with feedback. Feedback significantly stimulates a shift in consumption only for those consumers with a lower green self-identity, while those with a strong green self-identity are not as responsive. Presumably, consumers with high levels of green self-identity have very elaborated knowledge and opinions about how consumption impacts the environment and climate. Consumers with high levels of green self-identity will therefore be less surprised by the feedback of their footprint and consequently the feedback will not bring them to new insights. Interestingly, this finding is in line, for example, with the effects of nudging, which are also particularly strong for consumers without clear preferences (Thaler and Sunstein, 2008).

6.2. Practical implications

Based on our findings, we propose the following implications for managers, application developers, and non-governmental organizations. First, our results show that any type of carbon emission feedback is beneficial, because it reduces consumers' performance uncertainty. However, feedback will be more effective when consumers' carbon emissions are relatively high, implying a high potential for consumers to reduce their consumption. It is pivotal for decision-makers to recognize that feedback can be constructive and, when selecting segments and processing requisite information, they should prioritize targeting customers with high carbon emissions.

Second, the effects of feedback differ across consumption domains for various reasons. In our research, we discovered that feedback is less efficient in the domain of mobility, while it evokes intentions to reduce the carbon footprint in other domains, such as housing activities and heating. Decision-makers should, therefore, learn about the domains where providing feedback is most effective. Combining the first and the second implication, it can be concluded that focusing on hot spots of specific consumers with high emissions and on domains where consumers are more willing and able to change could be a good start to initiate behavioral changes toward more sustainability.

Third, feedback on carbon emissions can exert positive effects across different applications. Nevertheless, CFTAs, in contrast to CFCs, enable practitioners to tailor feedback and individualize interventions based on the monitored feedback. For instance, CFTAs could facilitate the display

of interventions that capitalize on the effects of eco-pride and eco-guilt (Mallett et al., 2013), by addressing consumers with pride-related prompts such as “You can be proud of yourself for reducing your footprint since last time.”

6.3. Limitations and future research directions

According to the three-horned dilemma proposed by Runkel and McGrath (1972), scholars face trade-offs and limitations with regard to the goals of generalizability, precision, and realism when choosing different study designs. Therefore, like every empirical study, the present study has some limitations that need to be addressed in further research. Moreover, as outlined below, the study opens fruitful avenues for more research on feedback effects and on CFTAs in sustainable consumption.

Owing to the sampling procedure, the generalizability of our findings is restricted. We invited a group of younger consumers to participate in our study, as this group helps gain initial insights on how feedback provided by CFTAs can shape consumption intention. Moreover, this group is not only potentially more concerned with the future implications of climate change, but also well educated in using apps, which is an important driver for using CFTAs (Hoffmann et al., 2022). This group therefore helps forecast the extent to which CFTAs will be effective once these tools are more common in the market. Nonetheless, the external validity of the finding is restricted and we call for more research with participants of different age groups. We expect that culture and socio-demographic status will also largely affect how consumers react to feedback provided by CFTAs. Rondoni and Grasso's (2021) literature review on the effectiveness of carbon footprint labels reveals that female and adult consumers as well as consumers with a higher income and educational level have a more positive attitude toward carbon footprint labels. These effects should also be tested for CFTAs.

Moreover, in order to consider the CFTA's effect for a larger set of consumers with different attitudes (not only the highly environmentally concerned), we actively asked the subjects to participate in the study and to use the CFTA. This might have created an artificial study setting, which reduces the ecological validity of the findings. It would be helpful to repeat our approach in an unobtrusive field study. For example, a future study might use the data that users entered while using the CFTA in their daily lives. Of course, this approach would potentially restrict the sample to consumers who are highly committed to environmental issues, who enjoy using apps, and who believe that digital tools can help environmental problems (Hoffmann et al., 2022). Yet, a triangulation of our study and a field study would be insightful.

Furthermore, it is necessary to consider the green intention-behavior gap (Munro et al., 2023). A relevant factor that causes the gap is the lack of information about the carbon emissions individuals produce (Joerß et al., 2021). The CFTA provides such information and it can continuously inform consumers about their emissions in different areas. Nonetheless, in this study, we asked the participants to state their intentions to reduce their carbon emission in specific domains after having gained feedback from the CFTA. We instructed them to be specific when they outlined their intentions. We did not simply ask whether they strive to reduce emissions, but we let them use the CFTA to specify exactly in which area they will reduce emissions by which amount. According to the correspondence principle, the relationship between intentions and behaviors is generally higher when they are both determined with a high level of specificity instead of generality (Ajzen and Fishbein, 1977). Nonetheless, this study could not control whether consumers actually translate these intentions into real behavior, and research shows that several additional factors can potentially disturb this relationship, such as subjective costs (Farjam et al., 2019), situational factors (Hoffmann

et al., 2019), or implicit sustainability associations (Mai et al., 2019; Luchs et al., 2010). We therefore call for more longitudinal research that controls the real behavior after using the CFTA.

Despite these limitations due to the necessary decision for a specific study design, this study's findings are promising and call for more research in the upcoming field of CFTAs. Particularly, we suggest more research with regard to the technological developments, the advantages of CFTAs over CFCs, and rebound effects. First, researchers should engage in technological developments to help consumers continue use CFTAs in their daily life. Compared to other STTs like pedometers, CFTAs are effortful and time consuming, as users have to actively enter their data daily, weekly, or at least regularly. For less committed users who fail to enter their data regularly, there are many missing values. The application used in this paper attempts to mitigate the problem of missing values by using default values. The application can use the data of prior periods (e.g., for heating) to insert data, for example, for heating in the next periods. Accordingly, users only have to indicate changes in their consumption at specific points in time. More research is needed on how to integrate data in a technical manner (e.g., with intersections to smart meters, e-cars, credit cards, e-retailing accounts). Integrating financial transaction data to calculate carbon emissions could be another way to improve the automatic actualization of the data basis (Andersson, 2020). Besides technological issues, this raises questions of data protection and security, which need to be resolved (Paluch and Tuzovic, 2019).

Second, the main difference between normal CFCs and CFTAs is that CFTAs track users' consumption and thus enable long-term behavioral changes and sustainable emission reductions. In the current study, participants could readily adjust their entries from the previous round due to the tracking feature of the CFTA, an option unavailable with a CFC. Despite this, participants still recorded their consumption over two rounds with only a short interval between them. As a result, we expect to see similar outcomes if the study were conducted using a CFC. Future research should consider having participants log their consumption in a CFTA over multiple rounds, incorporating time lags between them. Adopting a longitudinal perspective where consumers can compare their current emissions to those from, for instance, six months prior, might prove more influential than the repeated use of a CFC, which does not provide a means to contrast emissions over time.

Third, longitudinal studies are also needed to track how consumers respond to repeated feedback and under which conditions they are able to maintain the stimulated consumption changes. Notably, past research has shown that pro-environmental and climate-friendly consumption in a particular domain could stimulate indirect rebound effects in other domains (Reimers et al., 2021). Feedback could arguably help counteract rebound effects at the consumer level, but it can also trigger rebound effects due to psychological mechanisms. Since CFTAs report carbon emission savings to consumers, this information could subsequently serve as a moral license for less sustainable behavior in other domains of consumption. In this context, a study by Tiefenbeck et al. (2013) showed that weekly feedback on individual water consumption can reduce it, but can at the same time lead to an increase in energy consumption. Presumably, different moderator variables, including attitudes, context, and product categories, will influence whether feedback leads to consistent or inconsistent climate-friendly behavior. CFTAs provide a suitable tool to run research to answer this question. CFTAs are the necessary technical solution that enables researchers to collect consumption data and feedback on resource consumption in as many consumption domains as possible, at the same time, and over a longer period of time.

7. Conclusion

This article is the first to investigate the potential of CFTAs to modify consumers' consumption habits by repeatedly informing them of their carbon emissions. The most significant finding of this study is that the feedback given in a CFTA can reduce carbon emissions. We found a general decrease by 23%. The impact varies by consumption category, ranging from a 12% reduction in mobility to a 35% reduction in household activities. Moreover, individual traits influence the effectiveness of CFTA usage. Whereas a strong perceived green self-efficacy amplifies the feedback's effect, a strong green self-identity diminishes it. Based on the results, it is recommended that decision-makers account for individual differences when endorsing such apps. By acknowledging all these factors, we theoretically expand the SHIFT framework (White et al., 2019) with a digital component and we provide practitioners and researchers with a tool to address all five psychological forces to foster and research sustainable consumer behavior. We call for more research that analyzes the effects of CFTAs on consumption behavior. Future research could delve deeper to identify more nuanced effects and probe ways to boost effectiveness in specific consumption areas and for consumers with particular personalities, beliefs, attitudes, and values.

Funding source

This work was supported by the German Federal Ministry of Education and Research (BMBF) as a part of the iReliefs project (grant FZK

01UT1706A) which belongs to the framework program Social-Ecological Research. The content of this publication lies within the responsibility of the authors.

CRediT authorship contribution statement

Stefan Hoffmann: Conceptualization, Methodology, Software, Formal analysis, Investigation, Resources, Data curation, Writing – original draft, Writing – review & editing, Visualization, Supervision, Project administration, Funding acquisition. **Wassili Lasarov:** Conceptualization, Methodology, Software, Investigation, Resources, Data curation, Writing – original draft, Writing – review & editing, Visualization, Project administration, Funding acquisition. **Hanna Reimers:** Methodology, Software, Writing – review & editing, Visualization, Project administration. **Melanie Trabant:** Writing – review & editing, Visualization.

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.

Data availability

Data will be made available on request.

Appendix

Table A1
Exemplary queries included in the CFTA along the main consumption domains.

Consumption domain	Query in CFTA	Entered values
General Input	How many m ² has your living area?	Numeric input
	How many adults live in your household?	Numeric input
	Which kind of electricity are you receiving?	1 = German electricity mix 2 = Ecoelectricity
Heating	What is your provider's main source of heating energy?	1 = Natural gas 2 = Liquid gas 3 = Heating oil 4 = Electricity (German electricity mix) 5 = Electricity (Ecoelectricity) 6 = District heating 7 = Hard coal 8 = Brown coal briquette
	How old is your heating system?	1 = Built before 1980 2 = Built after 1980 3 = Built after 1995 4 = Built after 2005
	Please describe your behavior around ventilation.	1 = Many windows permanent tilt 2 = Some windows permanent tilt 3 = Intermittent ventilation 4 = Ventilation system 5 = None
	A man (a woman) consumes on average around 230g (278g) of vegetables per day. How would you estimate your amount of consumption in comparison?	1 = no consumption 2 = much less 3 = less 4 = about the same 5 = more 6 = much more
	What importance do you assign to the organic grade of the subsequent foods?	1 = not important 2 = important 3 = very important
Food	What importance do you assign to the regionality of the subsequent foods?	1 = not important 2 = important 3 = very important
	Do you have a bathtub?	1 = Yes 2 = No
	How often do you take a bath per week?	Numeric input
	How large is your bathtub?	1 = small bathtub 2 = medium bathtub 3 = large bathtub
Household	What kind of engine does your car have?	1 = Gasoline 2 = Diesel 3 = Natural gas 4 = Liquid gas 5 = Hybrid 6 = Electric car
Mobility		

(continued on next page)

Table A1 (continued)

Consumption domain	Query in CFTA	Entered values
	How many kilometers did you travel with this car on average per week for the following purposes? [shopping/commute/free time/vacation]?	Numeric input
	On average, how many miles have you traveled by the following means of transportation for each purpose? [shopping/commute/free time/vacation; Public bus, City train, Bicycle, E-bike, by foot, Motorcycle, etc]	Numeric input

Table A2

Reflective Multi-Item Measurement Scales.

Scale/Item	Loading
<i>Technology as solution belief</i> ($\alpha = .826$, CR = .718, AVE = .562, $r_{\max}^2 = .153$)	
Innovative technology helps solve problems.	.670
Innovative technology assists me in consuming sustainably.	.872
With the help of the right technology, we are able to live sustainably.	.822
<i>Green self-efficacy</i> ($\alpha = .861$, CR = .924, AVE = .585, $r_{\max}^2 = .164$)	
I can manage to reduce my carbon footprint	
even if I have to learn something.	.754
even if I have to consciously pay attention to it in many situations.	.884
even if I have to make a detailed plan for it.	.781
even if I have to rethink my entire consumer behavior.	.760
<i>Green self-identity</i> ($\alpha = .847$, CR = .828, AVE = .710, $r_{\max}^2 = .453$)	
Consuming in an environmentally conscious way is an important part of my personality.	.938
I am a person who acts in an environmentally friendly way.	.765
When I shop, I usually choose environmentally friendly products.	.735
<i>Negative emotions</i> ($\alpha = .878$, CR = .732, AVE = .485, $r_{\max}^2 = .125$)	
Guilt	.789
Shame	.884
Remorse	.905
Obligation	.505
Irritation	.759
<i>Positive emotions</i> ($\alpha = .794$, CR = .781, AVE = .481, $r_{\max}^2 = .453$)	
Joy	.514
Pride	.730
Confidence	.746
Belonging	.789

Notes. Factor loadings based on confirmatory factor analysis with AMOS 28.0 (maximum likelihood estimation). α = Cronbach's alpha, CR = composite reliability, AVE = average variance extracted, r_{\max}^2 = highest squared correlation of this construct with all other constructs. If AVE > r_{\max}^2 discriminant validity is given according to [Fornell and Larcker \(1981\)](#).

Table A3

Domain-specificity of Feedback Effects (Relative Differences, in %).

Feedback	Heating			Food			Household			Mobility		
	β	T	p	β	T	p	β	T	p	β	T	p
Heating	.126+	1.813	.071	-.005	-.076	.939	.066	.968	.334	.011	.161	.872
Food	-.102	-1.463	.145	.186**	2.673	.008	-.126	-1.856	.065	-.022	-.309	.757
Household	.046	.667	.506	.042	.605	.546	.263***	3.878	.000	.078	1.108	.269
Mobility	.118+	1.721	.087	-.057	-.825	.410	.057	.848	.397	.118 +	1.703	.090
F	2.410***			2.323+			5.208***			1.257		
R ²	.044			.042			.090			.023		
R ² adj	.026			.024			.073			.005		

Notes. OLS regression. DV: carbon footprint difference (relative, equation (2)). Level of significance: + $p < .10$, * $p < .05$, ** $p < .01$, *** $p < .001$.

Appendix for App Screenshots

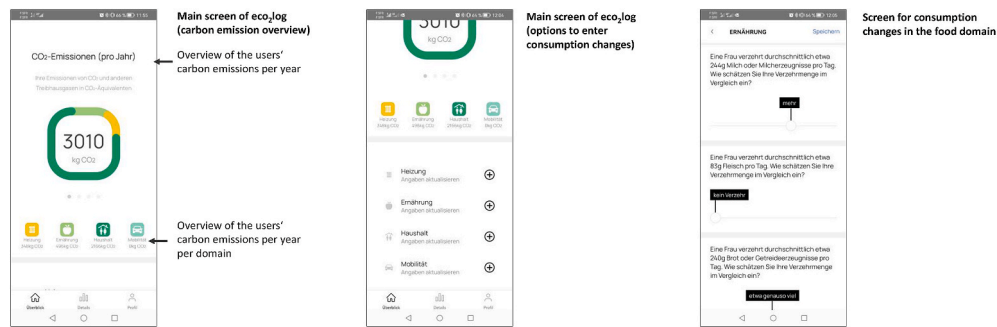


Fig. A1. Screenshots of the App.

References

- Abrahamse, W., Steg, L., Vlek, C., Rothengatter, T., 2007. The effect of tailored information, goal setting, and feedback on household energy use, energy related behaviors, and behavioral determinants. *J. Environ. Psychol.* 27 (4), 265–276.
- Ajzen, I., Fishbein, M., 1977. Attitude-behavior relations: a theoretical analysis and review of empirical research. *Psychol. Bull.* 84 (5), 888–918.
- Akenji, L., Bengtsson, M., Toivi, V., Lettenmeier, M., Fawcett, T., Parag, Y., Saheb, Y., Coote, A., Spangenberg, J.H., Capstick, S., Gore, T., Coscieme, L., Wackernagel, M., Kenner, D., 2021. 1.5-Degree Lifestyles: towards A Fair Consumption Space for All. Hot or Cool Institute, Berlin.
- Andersson, D., 2020. A novel approach to calculate individuals' carbon footprints using financial transaction data—App development and design. *J. Clean. Prod.* 256, 120396.
- Angosto, S., García-Fernández, J., Valantine, I., Grimaldi-Puyana, M., 2020. The intention to use fitness and physical activity apps: a systematic review. *Sustainability* 12 (16), 6641.
- Arbuckle, J.L., 2019. IBM SPSS Amos 26 User's Guide. IBM Corp.
- Attari, S.Z., DeKay, M.L., Davidson, C.I., de Bruin, W.B., 2010. Public perceptions of energy consumption and savings. In: *Proceedings of the National Academy of Sciences of the United States of America*, vol. 107, pp. 16054–16059.
- Attig, C., Franke, T., 2020. Abandonment of personal quantification: a review and empirical study investigating reasons for wearable activity tracking attrition. *Comput. Hum. Behav.* 102, 223–237.
- Audia, P.G., Locke, E.A., 2003. Benefiting from negative feedback. *Hum. Resour. Manag. Rev.* 13 (4), 631–646.
- Bandura, A., 2012. On the functional properties of perceived self-efficacy revisited. *J. Manag.* 38 (1), 9–44.
- Barbarossa, C., De Pelsmacker, P., 2016. Positive and negative antecedents of purchasing eco-friendly products: a comparison between green and non-green consumers. *J. Bus. Ethics* 134, 229–247.
- Baumeister, R.F., 2002. Reflections and reviews impulsive purchasing, and consumer behavior. *J. Consum. Res.* 28 (3), 670–677.
- Baumgartner, H., Homburg, C., 1996. Applications of structural equation modeling in marketing and consumer research: a review. *Int. J. Res. Market.* 13 (2), 139–161.
- BBC, 2023. Six ways to lower your carbon emissions quickly. <https://www.bbc.com/future/article/20230421-what-are-the-best-ways-to-reduce-carbon-footprint>, 09.15.2023.
- Beattie, G., 2012. Psychological effectiveness of carbon labelling. *Nat. Clim. Change* 2 (4), 214–217.
- Bennett, N., Herold, D.M., Ashford, S.J., 1990. The effects of tolerance for ambiguity on feedback-seeking behavior. *J. Occup. Psychol.* 63, 343–348.
- Berger, M., Lange, T., Stahl, B., 2022. A digital push with real impact-mapping effective digital nudging elements to contexts to promote environmentally sustainable behavior. *J. Clean. Prod.*, 134716.
- Buchanan, K., Russo, R., Anderson, B., 2015. The question of energy reduction: the problem(s) with feedback. *Energy Pol.* 77, 89–96.
- Büchs, M., Bahaj, A.S., Blunden, L., Bourikas, L., Falkingham, J., James, P., Kamanda, M., Wu, Y., 2018. Promoting low carbon behaviours through personalised information? Long-term evaluation of a carbon calculator interview. *Energy Pol.* 120, 284–293.
- Cadarso, M.Á., Gomez, N., López, L.A., Tobarra, M.Á., 2016. Calculating tourism's carbon footprint: measuring the impact of investments. *J. Clean. Prod.* 111, 529–537.
- Cameron, L.D., Brown, P.M., Chapman, J.G., 1998. Social value orientations and decisions to take proenvironmental action 1. *J. Appl. Soc. Psychol.* 28 (8), 675–697.
- Camilleri, A.R., Larrick, R.P., Hossain, S., Patino-Echeverri, D., 2019. Consumers underestimate the emissions associated with food but are aided by labels. *Nat. Clim. Change* 9 (1), 53–58.
- Capstick, S., Whitmarsh, L., Poortinga, W., Pidgeon, N., Upham, P., 2015. International trends in public perceptions of climate change over the past quarter century. *Wiley Interdiscipl. Rev.: Clim. Change* 6 (1), 35–61.
- Carrington, M.J., Neville, B.A., Whitwell, G.J., 2010. Why ethical consumers don't walk their talk: towards a framework for understanding the gap between the ethical purchase intentions and actual buying behaviour of ethically minded consumers. *J. Bus. Ethics* 97 (1), 139–158.
- Carrus, G., Passafaro, P., Bonnes, M., 2008. Emotions, habits and rational choices in ecological behaviours: the case of recycling and use of public transportation. *J. Environ. Psychol.* 28 (1), 51–62.
- CBC, 2020. How to make your online shopping less of an environmental or carbon footprint mess. <https://www.cbc.ca/radio/costofliving/you-ve-got-mail-looking-at-delivery-from-shippers-to-drivers-to-receivers-1.5836658/how-to-make-your-online-shopping-less-of-an-environmental-or-carbon-footprint-mess-1.5836703>, 09.15.2023.
- Clayton, S., 2003. Environmental Identity: a conceptual and an operational definition. In: Clayton, S., Opatow, S. (Eds.), *Identity and the Natural Environment: the Psychological Significance of Nature*. MIT Press, Cambridge, MA.
- Collins, A., Galli, A., Hipwood, T., Murthy, A., 2020. Living within a one planet reality: the contribution of personal footprint calculators. *Environ. Res. Lett.* 15 (2), 025008.
- Cronbach, L.J., 1951. Coefficient alpha and the internal structure of tests. *Psychometrika* 16 (3), 297–334.
- Deloitte, 2022. How Consumers Are Embracing Sustainability, Findings Based on a Consumer Survey Carried Out by the Market Research Agency. YouGov, on Deloitte's behalf. <https://www2.deloitte.com/uk/en/pages/consumer-business/articles/sustainable-consumer.html>. (Accessed 10 May 2023).
- Delmas, M.A., Fischlein, M., Asensio, O.I., 2013. Information strategies and energy conservation behavior: a meta-analysis of experimental studies from 1975 to 2012. *Energy Pol.* 61, 729–739.
- Dermody, J., Koenig-Lewis, N., Zhao, A.L., Hanmer-Lloyd, S., 2018. Appraising the influence of pro-environmental self-identity on sustainable consumption buying and curtailment in emerging markets: evidence from China and Poland. *J. Bus. Res.* 86, 333–343.
- ElHaffar, G., Durif, F., Dubé, L., 2020. Towards closing the attitude-intention-behavior gap in green consumption: a narrative review of the literature and an overview of future research directions. *J. Clean. Prod.* 275, 122556.
- Etkin, J., 2016. The hidden cost of personal quantification. *J. Consum. Res.* 42 (6), 967–984.
- Farjam, M., Nikolaychuk, O., Bravo, G., 2019. Experimental evidence of an environmental attitude-behavior gap in high-cost situations. *Ecol. Econ.* 166, 106434.
- Fischer, C., 2008. Feedback on household electricity consumption: a tool for saving energy? *Energy Effic.* 1 (1), 79–104.
- Fornell, C., Larcker, D.F., 1981. Evaluating structural equation models with unobservable variables and measurement error. *J. Market. Res.* 18 (1), 39–50.
- Frijda, N.H., 2007. What might emotions be? Comments on the Comments. *Soc. Sci. Inf.* 46 (3), 433–443.
- Gadema, Z., Oglethorpe, D., 2011. The use and usefulness of carbon labelling food: a policy perspective from a survey of UK supermarket shoppers. *Food Pol.* 36 (6), 815–822.
- Gifford, R., 2011. The dragons of inaction: psychological barriers that limit climate change mitigation and adaptation. *Am. Psychol.* 66 (4), 290–302.
- Gram-Hanssen, K., Christensen, T.H., 2012. Carbon calculators as a tool for a low-carbon everyday life? *Sustain. Sci. Pract. Pol.* 8 (2), 19–30.
- Gregory-Smith, D., Smith, A., Winkhofer, H., 2013. Emotions and dissonance in 'ethical' consumption choices. *J. Market. Manag.* 29 (11–12), 1201–1223.
- Grinstein, A., Kodra, E., Chen, S., Sheldon, S., Zik, O., 2018. Carbon innuery. *PLoS One* 13 (5), e0196282.
- Haidt, J., 2003. The moral emotions. In: Davidson, R.J., Scherer, K.R., Goldsmith, H.H. (Eds.), *Handbook of Affective Sciences*. Oxford University Press, Oxford, UK, pp. 852–870.
- Hair Jr., J.F., Black, W.C., Babin, B.J., Anderson, R.E., 2018. *Multivariate Data Analysis*, eighth ed. Cengage.
- Harrington, D., 2009. *Confirmatory Factor Analysis*. Oxford university press.

- Haws, K.L., Winterich, K.P., Naylor, R.W., 2014. Seeing the world through GREEN-tinted glasses: green consumption values and responses to environmentally friendly products. *J. Consum. Psychol.* 24 (3), 336–354.
- Hayes, A.F., 2017. Introduction to Mediation, Moderation, and Conditional Process Analysis: A Regression-Based Approach, second ed. Guilford publications.
- Higgins, E.T., Friedman, R.S., Harlow, R.E., Idson, L.C., Ayduk, O.N., Taylor, A., 2001. Achievement orientations from subjective histories of success: promotion pride versus prevention pride. *Eur. J. Soc. Psychol.* 23 (3), 3–23.
- Hoffmann, S., Mai, R., Lasarov, W., Krause, J.S., Schmidt, U., 2019. Hungry bellies have no ears. How and why hunger inhibits sustainable consumption. *Ecol. Econ.* 160, 96–104.
- Hoffmann, S., Lasarov, W., Reimers, H., 2022. Carbon footprint tracking apps. What drives consumers' adoption intention? *Technol. Soc.* 69, 101956.
- Hosta, M., Zabkar, V., 2021. Antecedents of environmentally and socially responsible sustainable consumer behavior. *J. Bus. Ethics* 171 (2), 273–293.
- Ivanova, D., Stadler, K., Steen-Olsen, K., Wood, R., Vita, G., Tukker, A., Hertwich, E.G., 2016. Environmental impact assessment of household consumption. *J. Ind. Ecol.* 20 (3), 526–536.
- Joerß, T., Hoffmann, S., Mai, R., Akbar, P., 2021. Digitalization as solution to environmental problems? When users rely on augmented reality-recommendation agents. *J. Bus. Res.* 128, 510–523.
- Jones, C.M., Kammen, D.M., 2011. Quantifying carbon footprint reduction opportunities for U.S. households and communities. *Environ. Sci. Technol.* 45, 4088–4095.
- Kahan, D.M., Peters, E., Wittlin, M., Slovic, P., 2012. The polarizing impact of science literacy and numeracy on perceived climate change risks. *Nat. Clim. Change* 2 (10), 732–735.
- Kaiser, F., 2006. A moral extension of the theory of planned behavior: norms and anticipated feelings of regret in conservationism. *Pers. Individ. Differ.* 41 (1), 71–81.
- Karapanos, E., Gouveia, R., Hassenzahl, M., Forlizzi, J., 2016. Wellbeing in the making: peoples' experiences with wearable activity trackers. *Psychol. Well-being* 6 (1), 1–17.
- Karjalainen, S., 2011. Consumer preferences for feedback on household electricity consumption. *Energy Build.* 43 (2), 458–467.
- Kaymaz, K., 2011. Performance feedback: individual based reflections and the effect on motivation. *Bus. Econ. Res. J.* 2 (4), 115–134.
- Kendel, A., Lazaric, N., Maréchal, K., 2017. What do people 'learn by looking' at direct feedback on their energy consumption? Results of a field study in Southern France. *Energy Pol.* 108, 593–605.
- Kleinhückelkotten, S., Neitzke, H.P., 2016. Berechnung individueller Pro-Kopf-Verbräuche natürlicher Ressourcen nach Konsumbereichen. In: Anlagenband zum Bericht Repräsentative Erhebung von Pro-Kopf-Verbräuchen natürlicher Ressourcen in Deutschland (nach Bevölkerungsgruppen). Bundesumweltamt, Bericht Nr. vol. 39. Dessau-Rosslau, 2016.
- Kim, B., Neff, R., 2009. Measurement and communication of greenhouse gas emissions from US food consumption via carbon calculators. *Ecol. Econ.* 69 (1), 186–196.
- Koenig-Lewis, N., Palmer, A., Dermody, J., Urbye, A., 2014. Consumers' evaluations of ecological packaging—Rational and emotional approaches. *J. Environ. Psychol.* 37, 94–105.
- Kok, A.L., Barendregt, W., 2021. Understanding the adoption, use, and effects of ecological footprint calculators among Dutch citizens. *J. Clean. Prod.* 326, 129341.
- Lalot, F., Quaiamzade, A., Falomir-Pichastor, J.M., Gollwitzer, P.M., 2019. When does self-identity predict intention to act green? a self-completion account relying on past behaviour and majority-minority support for pro-environmental values. *J. Environ. Psychol.* 61, 79–92.
- Levine, D.S., Strube, M.J., 2012. Environmental attitudes, knowledge, intentions and behaviors among college students. *J. Soc. Psychol.* 152 (3), 308–326.
- Li, J., Zhang, D., Su, B., 2019. The impact of social awareness and lifestyles on household carbon emissions in China. *Ecol. Econ.* 160, 145–155.
- Luchs, M.G., Naylor, R.W., Irwin, J.R., Raghunathan, R., 2010. The sustainability liability: potential negative effects of ethicality on product preference. *J. Market.* 74 (5), 18–31.
- Lupton, D., 2016. The diverse domains of quantified selves: self-tracking modes and dataveillance. *Econ. Soc.* 45 (1), 101–122.
- Luszczynska, A., Scholz, U., Schwarzer, R., 2005. The general self-efficacy scale: multicultural validation studies. *J. Psychol.* 139 (5), 439–457.
- Mai, R., Hoffmann, S., Balderjahn, I., 2021. When drivers become inhibitors of organic consumption: the need for a multistage view. *J. Acad. Market. Sci.* 49, 1151–1174.
- Mai, R., Hoffmann, S., Hoppert, K., Schwarz, P., Rohm, H., 2015. The spirit is willing, but the flesh is weak: the moderating effect of implicit associations on healthy eating behaviors. *Food Qual. Prefer.* 39, 62–72.
- Mai, R., Hoffmann, S., Lasarov, W., Buhs, A., 2019. Ethical products=less strong: how explicit and implicit reliance on the lay theory affects consumption behaviors. *J. Bus. Ethics* 158 (3), 659–677.
- Mallett, R.K., Melchiori, K.J., Strickroth, T., 2013. Self-confrontation via a carbon footprint calculator increases guilt and support for a proenvironmental group. *Ecopsychology* 5 (1), 9–16.
- McCalley, L.T., Midden, C.J., 2002. Energy conservation through product-integrated feedback: the roles of goal-setting and social orientation. *J. Econ. Psychol.* 23 (5), 589–603.
- McGouran, C., Prothero, A., 2016. Enacted voluntary simplicity—Exploring the consequences of requesting consumers to intentionally consume less. *Eur. J. Market.* 50 (1/2), 189–212.
- McKee, D., Simmers, C.S., Licata, J., 2006. Customer self-efficacy and response to service. *J. Serv. Res.* 8 (3), 207–220.
- McClelland, L., Cook, S.W., 1979. Energy conservation effects of continuous in-home feedback in all-electric homes. *J. Environ. Syst.* 9 (2), 169–173.
- Munro, P., Kapitan, S., Wooliscroft, B., 2023. The sustainable attitude-behavior gap dynamic when shopping at the supermarket: a systematic literature review and framework for future research. *J. Clean. Prod.* 426, 138740.
- Mulrow, J., Machaj, K., Deanes, J., Derrible, S., 2019. The state of carbon footprint calculators: an evaluation of calculator design and user interaction features. *Sustain. Prod. Consum.* 18, 33–40.
- Nielsen, K.S., Stern, P.C., Dietz, T., Gilligan, J.M., van Vuuren, D.P., Figueroa, M.J., et al., 2020. Improving climate change mitigation analysis: a framework for examining feasibility. *One Earth* 3 (3), 325–336.
- Onwezen, M.C., Bartels, J., Antonides, G., 2014. The self-regulatory function of anticipated pride and guilt in a sustainable and healthy consumption context. *Eur. J. Soc. Psychol.* 44 (1), 53–68.
- Paluch, S., Tuzovic, S., 2019. Persuaded self-tracking with wearable technology: carrot or stick? *J. Serv. Market.* 33 (4), 436–448.
- Pantzar, M., Ruckenstein, M., 2015. The heart of everyday analytics: emotional, material and practical extensions in self-tracking market. *Consum. Mark. Cult.* 18 (1), 92–109.
- Pelozo, J., White, K., Shang, J., 2013. Good and guilt-free: the role of self-accountability in influencing preferences for products with ethical attributes. *J. Market.* 77 (1), 104–119.
- Pristl, A.C., Kilian, S., Mann, A., 2021. When does a social norm catch the worm? Disentangling social normative influences on sustainable consumption behaviour. *J. Consum. Behav.* 20 (3), 635–654.
- Reimers, H., Jacksohn, A., Appenfeller, D., Lasarov, W., Hüttel, A., Rehndanz, K., Balderjahn, I., Hoffmann, S., 2021. Indirect rebound effects on the consumer level: a state-of-the-art literature review. *Philos. Technol.* 3, 100032.
- Renner, B., Knoll, N., Schwarzer, R., 2000. Age and body make a difference in optimistic health beliefs and nutrition behaviors. *Int. J. Behav. Med.* 7 (2), 143–159.
- Rockström, J., Steffen, W., Noone, K., Persson, Å., Chapin, F.S., Lambin, E.F., Lenton, T. M., Scheffer, M., et al., 2009. A safe operating space for humanity. *Nature* 461 (7263), 472–475.
- Rondoni, A., Grasso, S., 2021. Consumers behaviour towards carbon footprint labels on food: a review of the literature and discussion of industry implications. *J. Clean. Prod.* 301, 127031.
- Runkel, P.J., McGrath, J.E., 1972. Research on Human Behavior: A Systematic Guide to Method, first ed. Rinehart and Winston.
- Salo, M., Mattinen-Yuryev, M.K., Nissinen, A., 2019. Opportunities and limitations of carbon footprint calculators to steer sustainable household consumption—Analysis of Nordic calculator features. *J. Clean. Prod.* 207, 658–666.
- Santarius, T., Soland, M., 2018. How technological efficiency improvements change consumer preferences: towards a psychological theory of rebound effects. *Ecol. Econ.* 146, 414–424.
- Sharon, T., 2017. Self-tracking for health and the quantified self: Re-articulating autonomy, solidarity, and authenticity in an age of personalized healthcare. *Philosophy & Technology* 30 (1), 93–121.
- Sproles, G.B., Kendall, E.L., 1986. Methodology for profiling consumers' decision-making styles. *J. Consum. Aff.* 22 (2), 267–279.
- Steffen, W., Richardson, K., Rockström, J., Cornell, S.E., Fetzer, I., Bennett, E.M., Biggs, R., Carpenter, S.R., et al., 2015. Planetary boundaries: guiding human development on a changing planet. *Science* 347 (6223).
- Stern, P.C., Dietz, T., 2020. A broader social science research agenda on sustainability: nongovernmental influences on climate footprints. *Energy Res. Social Sci.* 60, 101401.
- Swan, M., 2013. The quantified self: fundamental disruption in big data science and biological discovery. *Big Data* 1 (2), 85–99.
- Tangney, J.P., Miller, R.S., Flicker, L., Barlow, D.H., 1996. Are shame, guilt, and embarrassment distinct emotions? *J. Pers. Soc. Psychol.* 70 (6), 1256–1269.
- Tangney, J.P., Stuewig, J., Mashek, D.J., 2007. Moral emotions and moral behavior. *Annu. Rev. Psychol.* 58, 345–372.
- Thaler, R.H., Sunstein, C.R., 2008. *Nudge: Improving Decisions about Health, Wealth, and Happiness*. Penguin.
- The Wall Street Journal, 2022. Can you reduce climate change with a credit card? What to know about buying carbon offsets. <https://www.wsj.com/articles/what-to-know-about-buying-carbon-offsets-11635418802>, 09.15.2023.
- Thøgersen, J., Nielsen, K.S., 2016. A better carbon footprint label. *J. Clean. Prod.* 125, 86–94.
- Tiefenbeck, V., Goette, L., Degen, K., Tasic, V., Fleisch, E., Lalive, R., Staake, T., 2016. Overcoming salience bias: how real-time feedback fosters resource conservation. *Manag. Sci.* 64 (3), 1458–1476.
- Tiefenbeck, V., Staake, T., Roth, K., Sachs, O., 2013. For better or for worse? Empirical evidence of moral licensing in a behavioral energy conservation campaign. *Energy Pol.* 57, 160–171.
- Tiefenbeck, V., Wörner, A., Schöb, S., Fleisch, E., Staake, T., 2019. Real-time feedback promotes energy conservation in the absence of volunteer selection bias and monetary incentives. *Nat. Energy* 4 (1), 35–41.
- Tukker, A., Jansen, B., 2006. Environmental impacts of products: a detailed review of studies. *J. Ind. Ecol.* 10 (3), 159–182.
- Tukker, A., 2006. Identifying priorities for environmental product policy. *J. Ind. Ecol.* 10 (3), 1–4.
- UN, 2015. Transforming our world: the 2030 agenda for sustainable development. URL: <https://sustainabledevelopment.un.org>.
- Vallacher, R.R., Wegner, D.M., 1989. Levels of personal agency: Individual variation in action identification. *J. Pers. Soc. Psychol.* 57 (4), 660–671.
- van Bussel, L.M., Kuijsten, A., Mars, M., Veer, P., 2022. Consumers' perceptions on food-related sustainability: a systematic review. *J. Clean. Prod.* 341, 130904.

- van der Werff, E., Steg, L., Keizer, K., 2013. It is a moral issue: the relationship between environmental self-identity, obligation-based intrinsic motivation and pro-environmental behaviour. *Global Environ. Change* 23, 1258–1265.
- van Zomeren, M., Spears, R., Leach, C.W., 2010. Experimental evidence for a dual pathway model analysis of coping with the climate crisis. *J. Environ. Psychol.* 30 (4), 339–346.
- Walton, T.N., Jones, R.E., 2018. Ecological identity: the development and assessment of a measurement scale. *Environ. Behav.* 50 (6), 657–689.
- Wang, J., Wu, L., 2016. The impact of emotions on the intention of sustainable consumption choices: evidence from a big city in an emerging country. *J. Clean. Prod.* 126, 325–336.
- Weber, H., Loschelder, D.D., Lang, D.J., Wiek, A., 2021. Connecting consumers to producers to foster sustainable consumption in international coffee supply-a marketing intervention study. *J. Market. Manag.* 37 (11–12), 1148–1168.
- West, S.E., Owen, A., Axelsson, K., West, C.D., 2016. Evaluating the use of a carbon footprint calculator: communicating impacts of consumption at household level and exploring mitigation options. *J. Ind. Ecol.* 20 (3), 396–409.
- Westskog, H., Winther, T., Sæle, H., 2015. The Effects of in-home displays. Revisiting the context. *Sustainability* 7 (5), 5431–5451.
- White, K., Habib, R., Hardisty, D.J., 2019. How to SHIFT consumer behaviors to be more sustainable: a literature review and guiding framework. *J. Market.* 83 (3), 22–49.
- Wiedmann, T., Minx, J., 2008. A definition of ‘carbon footprint’. *Econ. Res. TrendsPsychol* 1, 1–11.
- Williams, L.A., DeSteno, D., 2008. Pride and perseverance: the motivational role of pride. *J. Pers. Soc. Ecol.* 94 (6), 1007–1017.
- Wittkowski, K., Klein, J.F., Falk, T., Schepers, J.J., Aspara, J., Bergner, K.N., 2020. What gets measured gets done: can self-tracking technologies enhance advice compliance? *J. Serv. Res.* 23 (3), 281–298.
- World Economic Forum, 2020. *The global risks report 2020*. URL: http://www3.weforum.org/docs/WEF_Global_Risk_Report_2020.pdf.
- Yan, M., Filieri, R., Raguseo, E., Gorton, M., 2021. Mobile apps for healthy living: factors influencing continuance intention for health apps. *Technol. Forecast. Soc. Change* 166, 120644.
- Zangheri, P., Serrenho, T., Bertoldi, P., 2019. Energy savings from feedback systems: a meta-studies’ review. *Energies* 12 (19), 3788.
- Zhang, X., Luo, L., Skitmore, M., 2015. Household carbon emission research: an analytical review of measurement, influencing factors and mitigation prospects. *J. Clean. Prod.* 103, 873–883.
- Zimmermann, L., 2021. “Your screen-time app is keeping track”: consumers are happy to monitor but unlikely to reduce smartphone usage. *J. Assoc. Consum. Res.* 6 (3), 377–382.