Gamifying Sustainability

Raising Carbon Footprint Awareness
Through Gamification:
The Carbon Footprint Movement

Mariana Nunes

Dissertation written under the supervision of Professor René Bohnsack.

Dissertation submitted in partial fulfilment of requirements for the MSc in Management with Specialization in Strategy and Entrepreneurship, at the Universidade Católica Portuguesa, June 14th, 2020.

Abstract

Extreme human-induced environmental pressures are being felt across the globe. Scientific evidence increasingly alerts for the urgent need to induce societal engagement in climate change mitigation to achieve carbon-reduction targets.
This thesis' overreaching purpose aimed at appraising the extent to which a gamification-based system may increase carbon literacy and empower individuals to adopt lower-carbon lifestyles.
Simultaneously, this study explores the hotspots where policy action should be taken to reduce the contextual barriers to more pro-environmental lifestyles. Given the multitude of factors influencing behaviors, the research herein described disaggregated national data to local levels.
To attain the set objectives, a gamified-survey tool was developed, as the primary learning and data collection instrument: **The Carbon Footprint Movement.**
Results showed carbon footprint was not a primary deliberation preceding everyday behavior and that respondents' misconceptions regarding the environmental effects of their actions prevailed. Additional findings also reinforced contextual factors further detached intentions from behaviors, intensifying the so-called value-action gap. Notwithstanding, participants reported carbon literacy increases (23%) and pledged imminent behavioral changes, over the course of the intervention.
This dissertation reinforces high-magnitude carbon emissions to be locked-in at the household level, and the potentiality of gamified interventions to unlock substantial reductions. However, it simultaneously unveils large potential savings to remain unfulfilled, suggesting active civic engagement also calls for wider structural adjustments
The methodology devised might be used to guide the development of future gamified interventions.

Keywords: Carbon literacy, carbon footprint, gamification, pro-environmental behavior, climate change, sustainability

Title: Gamifying Sustainability. Raising Carbon Footprint Awareness Through Gamification: The Carbon Footprint Movement.

Author: Mariana Nunes

Abstract (Portuguese)

Pressões ambientais extremas estão a ser sentidas em todo o mundo. Evidências científicas alertam para a necessidade urgente do envolvimento da sociedade na mitigação das alterações climáticas.
Esta dissertação visa avaliar em que medida um sistema baseado na gamificação pode aumentar a literacia de carbono e capacitar os indivíduos para adotarem comportamentos mais sustentáveis.
Paralelamente, este estudo explora os pontos críticos em que devem ser tomadas medidas para a redução de obstáculos a estilos de vida mais pró-ambientais.
Para atingir os objetivos estabelecidos, foi desenvolvido um instrumento de aprendizagem e de recolha de dados: **The Carbon Footprint Movement.**
Os resultados indicam que a tomada diária de decisões raramente é precedida de uma deliberação sobre a respetiva pegada de carbono, que as pessoas mantêm ideias erradas sobre a eficácia ambiental das suas ações, e que os fatores contextuais desassociam ainda mais as intenções dos comportamentos.
Não obstante, os participantes reportaram aumentos em literacia de carbono (23%) e afirmaram mudanças comportamentais ao longo da intervenção.
Esta dissertação destaca a potencialidade de intervenções gamificadas na redução substancial de emissões de carbono, bloqueadas ao nível doméstico. No entanto, este estudo revela que um envolvimento cívico mais ativo no combate às alterações climáticas exige, simultaneamente, ajustes estruturais fundamentais.
A metodologia descrita poderá ser utilizada para orientar o desenvolvimento de futuras intervenções gamificadas.

Palavras-chave: Literacia de carbono, pegada de carbono, gamificação, comportamento sustentável, alterações climáticas, sustentabilidade

Título: Gamificar a Sustentabilidade. Sensibilização para a Pegada de Carbono através da Gamificação: The Carbon Footprint Movement

Autor: Mariana Nunes

Acknowledgements

I would like to thank to my thesis supervisor, Professor René Bohnsack for his guidance and support, and to María del Mar Martínez-Bravo for her availability and indispensable help.

I would like to thank to all participants of The Carbon Footprint Movement who patiently filled in the surveys. Without them this research would not have been possible.

Last but not least, I would also like to express my profound gratitude to my family and friends for all their patient and encouragement.

Table of Contents

List of Tables

List of Figures

List of Abbreviations

TCFM	The Carbon Footprint Movement
GHG	Greenhouse gas
PEB	Pro-environmental behavior
CF	Carbon footprint

1 Introduction

1.1 Problem Definition and Relevance

Mounting scientific evidence has remarked climate change as one of the defining crises of our time. Extreme human-induced environmental pressures are being felt across the globe. Ranging from acute weather events, icecaps melting to coastal flooding, the climate change phenomena is no longer a scientific extrapolation, but a threat to the planet's environmental, social, and economic stability (IPCC, 2016).

Global consensus among the scientific community ascertained climate-system changes to be substantially driven by human behaviors, namely greenhouse gas (GHG) emitting activities, as burning fossil fuels. Human societies' environmental impact is more conspicuous than ever, and the unprecedented times the world was facing at the time of this study, brought forth further compelling evidence on the matter. One could not proceed without briefly alluding to the current pandemic crisis and the effects it has disclosed. The novel coronavirus has brought the world to a virtual standstill. Forcing lockdowns and activities to freeze, the pandemic caused unprecedented social disruption and wreaked havoc in markets. Moreover, the environmental changes wrought by Covid-19 are also global and unprecedented. Sentinel-5P satellite data unveiled steep falls in nitrogen dioxide air pollution levels (primarily released from burning fossil fuels). The human footprint has suddenly plummeted. According to the Environmental and Energy Study Institute, road traffic faded, air traffic halved, and leading environmental indicators, after decades of steady deterioration, appeared to have come to a halt, if not improved.

This allusion aim was not to elaborate on the pandemic environmental impacts, as the former markedly hinge on the political decisions enacted upon what follows. Moreover, the hard to fathom spiraling death toll immediately conveys the virus as no reliable way to tackle the climate crisis. The present conjecture was instead mentioned as, according to experts, it occasioned a glimpse of a world no longer reckoned on fossil fuels, making the interconnection among human and planetary health more obvious than ever.

Albeit a silver lining might arise as an inflection point for world leaders to chart a course towards a healthier world, comprehensive economic model changes are rather farfetched. Therefore, as household consumption is among the greatest GHG emissions' drivers, a gradual transition of individual consumption patterns may pave the way towards a low-carbon society (Druckman & Jackson, 2015).

Hertwich and Peters (2009) and Ivanova et al. (2016) tracked down 60-70% of GHG emissions to personal consumption, with over a-third entirely traced to household's energy use and private travel. Individuals are challenged with an imperative call for action. However, recent research has also been alerting for widespread environmental awareness, bounded by a limited understanding and behavioral engagement. Indeed, sustainable consumption has been referred to as the environmental policy "holy grail" (Jones & Kammen, 2011), pinpointing the complexity of human consumption. Broader literature on pro-environmental behavior stressed responses to be oftentimes limited to domestic energy preservation or recycling (Whitmarsh, 2009b).

Regardless of the assortment of factors constraining one's pro-environmental behavior, a thorough appraisal unveiled reluctance to act as primarily caused by an attitude-behavior gap, resulting, partially, from a general information deficit (Kollmuss & Agyeman, 2010). Whereas evidence displayed general awareness on climate change, countless researchers revealed prevailing ineptitudes to link the former conceptualizations to one's personal choices. Stern and Gardner (2008), for instance, highlighted people's misconceptions about the relative impacts of behaviors on emissions.

As only informed dwellers may trigger behavior change and rally for the environmental cause, informational approaches, enlightening individuals on their carbon emissions, are perhaps crucially the foundation to bridge this knowledge deficit. The former brings forth the term carbon literacy, only recently defined in the literature, and resorted to through this paper course (Howell, 2018).

Yet, one-way information provision alone is insufficient to trigger change as, beyond understanding, people need to care and be motivated to fully engage. Thus, there is a growing interest by academics, policymakers, and practitioners, in developing more participatory methods. Exploratory research substantiated the eminence of tools that not only inform users of one's footprint and suggest reduction pathways, but that do so while empowering them through immediate feedback, contextualized information, and social connection opportunities (West et al., 2016).

Following this line of thinking, previous research has validated gamification efficacy on raising awareness and motivating people to pursue more sustainable footprints (Seaborn & Fels, 2015). Congruent with literature recommendations on gamification, carbon calculators, and climate change education, this paper purports to formulate a gamification-based social-system to spur carbon literacy. The Carbon Footprint Movement (TCFM) was accordingly designed and stands out as a promising approach to stimulate pro-environmental behavior changes.

However, ceasing our analysis here would indicate a myopic approach to the matter. This study goes further into remarking actionable information and motivation to act are important pre-requisites, but often insufficient to secure engagement. The previously mentioned knowledge-action gap is frequently exacerbated by broader economic, social, or structural impediments to lower-carbon lifestyles (Lorenzoni et al. 2007). Structural strategies and supportive infrastructures are simultaneously needed. Hence, this intervention was twofold. Besides providing an engaging, information-providing experience, this system was designed to be attentive to its users. Lastly, the elaboration of such use case disaggregated national data to local levels, signaling the hotspots where consumer policy action should be taken to reduce contextual barriers of dissonance.

1.2 Research Objectives and Questions

At the outset, this study's purpose was to explore the gamification process from a pro-environmental behavioral dimension and elaborate a bottom-up consumption-based intervention to expand carbon literacy. Built upon theoretical and empirical findings, TCFM might be positioned as part of the discussion on how to expose the invisible impacts of consumption and steer sustainable patterns.

One may claim a foremost contribution of this thesis to stem from the design of a new artifact: a gamified intervention of purposeful engagement and environmental education. Accordingly, this intervention was, at its heart, crafted as a participatory approach directed at arousing participants' attention, securing commitment, and deepen involvement, through the process of data collection.

Therefore, this thesis' aims, and objectives may be guided by the following research questions:

RQ1: Is there a baseline value-action gap concerning lower-carbon behavior adoption?

RQ2: Is there a link between carbon literacy, carbon footprint, and barriers to pro-environmental behavior?

RQ3: What are the potential outcomes of applying gamification for the purpose of carbon literacy enhancement?

To sum up, this thesis will start with a literature review section, whereby fundamental terminology is defined, and the current state of research is clarified. The methodology section follows, describing the intervention's design, specific measurement methods, and instruments leveraged. The fourth section unfolds findings and a results' discussion. The last chapter covers conclusions, limitations on this study, and outlines areas for future research.

2 Theoretical Background

2.1 Runaway Climate Change: The Impacts of Household Consumption

Climate change is one of the pressing challenges our society is currently facing. The imbalances caused among natural systems are extensive and severe, ranging from extreme weather phenomena to disrupted water systems (IPCC, 2016). Urgent, global, and local, efforts are thus needed to tame climate change, preventing temperatures from increasing above critical thresholds. Climate change has attained prime concern on international political agendas: under the Paris Agreement (UNFCCC, 2015), 195 nations agreed to limit the increase in global temperatures below 2ºC, above pre-industrial temperatures. However, most reduction frameworks conjecture the upcoming leverage of novel technologies to stay under the 2ºC level (Wynes & Nicholas, 2017). Experts and policymakers increasingly agree under current pathways the rise in average temperatures could overhaul the critical 2°C threshold shortly after 2060 and persistently increase, amplifying the likelihood of large-scale irreversible climate changes (European Commission, 2019).

This calls for immediate strong actions to curb emissions. International and national policies are gradual, and enacting changes among locked-in infrastructures and institutions often takes time. Contrarily, consumption patterns' shifts are likely more easily prompted (e.g. automobile reliance can more quickly be reduced, whereas improved power plant efficiency occurs on a decadal time-frame) (Wynes & Nicholas, 2017). On top of that, a myriad of environmental problems is partially, if not completely, the result of unsustainable human behavior. For instance, Hertwich and Peters (2009) reported 72% of global GHG emissions to result from household consumption. From the latter, the authors stated 20% was related to food and 17% to mobility. Notwithstanding, mankind's action may contribute to reverse or minimize these issues. For instance, evidence suggested the increased adoption of plant-based diets could lessen emissions by up to 80% (Springmann et al., 2018). An alternative approach to climate change mitigation can be gained if the analysis is taken from a consumption perspective.

This reasoning has been widely exploited in textbooks and other publications. However, these studies typically focus on a sole consumption tier, such as transport (Girod et al., 2012), food (Springmann et al., 2018) or household (Abrahamse et al., 2005). To methodically proceed into the conceptualization of societal engagement in mitigation, one must review existing measurement methods to gauge empirical impacts.

2.2 Carbon Footprint: Human Action as a Behavioral Wedge

CO2 emissions' measurement typically takes a production-accounting method. Often applied for domestic and international targets and reports, this approach only captures territorial emissions resulting from household and industrial activity. In contrast, consumption-based accounting tracks emissions among the products' global supply chain, fully measuring domestic consumption impacts. Often referred to as carbon footprint, consumption-based emissions relate directly to households' lifestyle choices.

The carbon footprint enables one to link domestic consumption to global GHG emissions. However, a lack of consensus often arises regarding which GHGs calculations comprise. While some scholars defined only carbon dioxide should be accounted for, further research advocated for the inclusion of other GHGs (Wiedmann & Minx, 2007; Wright et al., 2011). Given the lack of consensus over emissions' assortment, one may follow Pandey et al. (2011) suggestion and set out carbon footprint as "the quantity of GHGs expressed in terms of CO2, emitted into the atmosphere by an individual, organization, process, product, or event from within a specified boundary" (p.138), whereas GHGs and boundaries are settled as claimed by the methodology adopted and the measurement purpose.

Despite these variations and resulting shortcomings, the main findings persist among this body of work: mobility (ground and air transport), food, and housing are the dominant sources of consumption-related environmental effects. Households' way of living has been widely noted as a key driver of natural resources' overconsumption, emphasizing individuals' vital role in any potential low-carbon transition. Understanding the underlying drivers of sustainable patterns remains complex and imprecise, and household consumption continues to grow (Eurostat, 2018).

2.3 Carbon Management: One More Awareness Gap

Recent research pointed to widespread climate change awareness but limited societal engagement. The latest edition of a survey, carried in 28 European Union Member States, signalized consistent findings, including increased awareness and concern (e.g. 93% think climate change is a serious issue), but of secondary importance when compared to other personal, social, or more tangible issues (European Commission, 2019).

The discrepancy between climate change awareness and behavioral response is aligned with the widely addressed value-action gap. Following the lead of environmental literature, the terms "behavior" and "action", along with "value", "belief" and "attitude" are used interchangeably through this work course.

This cognition-action gap stems greatly from the puzzling human nature. Several studies have already addressed the lack of robustness proceeding the knowledge-action relationship. Thøgersen (2005) pointed societal infrastructure and alternatives' availability among factors constraining consumers' choices. Jackson (2005) went further by arguing changing behaviors was challenging as social and institutional contexts often lock consumers into unsustainable lifestyles.

The latter purported to show human behaviors arise as the most paradoxical component of the climate change system, due to the variety of factors influencing behavior. Indeed, numberless endeavors have been taken since the 1970s, by environmental psychologists to demystify the drivers of pro-environmental behaviors. However, as suggested by Gifford et al. (2011), existing models alone appear insufficient to capture the complexities of behaviors. Early models assumed causality from environmental knowledge to concern and pro-environmental behavior, the so-called knowledge deficit models, but have been utterly discredited. Newer studies have followed the reasoning of more used theories. For instance, aligned with Stern (2000) environmental intent VBN theory, Attari et al., (2010) showed willingness to adopt voluntary actions to climate mitigation was higher among those displaying higher environmental values.

Writers have provided plausible theoretical explanations, but to date, empirical validations seemed equivocal. Additionally, to exacerbate the gap in question, research on public understanding found individuals often harbor misconceptions regarding the impacts their actions entail on emissions. For instance, small changes as recycling or turning off lights were often suggested as the most effective actions in tackling climate changes, whereas activities displaying high potential for emissions' reductions (meat-eating or flying) tended to be underestimated or less mentioned (Truelove & Parks, 2012; Whitmarsh et al., 2011).

Therefore, a more meaningful discussion calls for the carbon literacy term. The latest attempt for a definition is by Howell (2018) who stated: "Carbon literacy is an individual's ability to obtain, understand and evaluate the relevant information necessary to make decisions with an awareness of the likely consequences regarding GHG emissions"(p.27). The term stems beyond knowledge, comprising skills, abilities, and motivations. Howell (2018) also claimed that even carbon-literate individuals might be unable or simply choose not to engage in GHGs' reduction actions. Climate change mitigation entangles a complex interplay of interpersonal, intrapersonal, and contextual factors that may vary significantly as a function of behaviors. This was essentially the argument advanced by Howell (2018) when reasoning emissions' reductions might not be an outcome of carbon literacy enhancement.

The latter does not diminish the importance of personal actions to reduce emissions, as the ultimate purpose of stimulating literacy is to promote low-carbon lifestyles. This implies people's ability to make decisions with a clear awareness of the likely repercussions. Therefore, the former presupposes carbon literacy essence to entail the following components: understanding GHG emissions' sources, understanding the relative impacts everyday activities entail on emissions, and ergo the skills and knowledge to assimilate the latter when making behavioral decisions. These are not the only literacy elements, but for the paper being, focus will be directed towards them.

This study field is progressively gaining traction, and recent research has gone further into defining a broad-ranging related concept. Whitmarsh et al. (2009) settled carbon capability as "The ability to make informed judgments and take effective decisions regarding the use and management of carbon, through individual behavior change and collective action"(p.2). The latter sets apart from the narrow-gauged literacy construct, implying carbon-capable individuals would appreciate and seek to influence the structural barriers to low-carbon societies. As further research is needed on constituents composing carbon capability, this paper scope will be confined to the literacy construct solely.

Thus, it will leverage on an interplay between Stern's (2000) four environmental factors (attitudes, contextual forces, personal capabilities, and habit) and the former literacy definition, to design and assess an intervention aiming to spread carbon literacy.

2.4 A Practice and Mitigation Gap: The Carbon Calculators Case

Despite the long-lasting scholars' disagreement on the effectiveness of different factors in pro-environmental promotion, a priority aim in the climate change agenda should be to engender in individuals an awareness of their negative impacts, while suggesting how to pursue more sustainable lifestyles.

Over the past decade, in tandem with urgent calls to reduce emissions, a proliferation of carbon calculators has occurred. Carbon calculators are potential mechanisms to address knowledge gaps by communicating behaviors' emissions. These tools consist of a software application that calculates from inputted information the contribution of activities in relation to one's carbon output.

The available literature on the development and application of calculators for citizens is limited. Empirical results from calculators' operationalizations in Germany, Spain, and Austria reported positive outcomes in terms of increased awareness, understanding of carbon impacts, and individual empowerment (Aichholzer et al., 2012). However, it was also reported by Lorenzoni et al. (2007) that providing people with environmental knowledge might be useful but ineffective to lessen emissions. A significant "practice gap" typically arises, as calculators commonly do not fully integrate carbon footprinting scholarly findings.

A review by Bottrill (2007) of thirty internet-based carbon calculators concluded most fell short in various aspects: accuracy and ongoing monitoring, personalized feedback, and opportunities to connect with others. Dissimilar studies also identified scope, consistency, and transparency as dimensions needing improvement. Specifically, these environmental learning tools are falling short in providing action-plans. Rather users are often presented with unranked advice lists and little information to discern and prioritize effective actions (Gardner & Stern, 2008). Additionally, while calculators abound, no calculation methodology consensus exists. Prior research has shown footprints produced for similar input assumptions may vary widely among calculators. This may not imply invalid results but might induce different responses and efforts' placement. To add on, calculators typically lack data transparency, often failing to publicly disclose the calculation engine (Kim & Neff, 2009).

Furthermore, given calculators' generalized focus on easy-to-perform actions, this study also identifies a significant mitigation gap between calculators' recommendations and individuals' lack of cognizance on the magnitudes of their emissions.

Following Wynes and Nicholas (2017) orientation, this paper attempts to start bridging these gaps by focusing on improving communication structures, to promote more effective emission-reduction strategies.

2.5 Towards the Gamification of Sustainability

For individuals to act as a catalyst for the needed decarbonization tacit by the 2°C target, providing information is vital but not enough. Information provision schemes alone tend to result in low-engagement rates, not being particularly effective at lessening emissions (West et al., 2016). Hence, more participatory mechanisms may enhance sustainable behaviors' promotion and adoption. Carbon calculators, when strategically designed, might constitute an effective mechanism for individual engagement, bridging individuals' lifestyles with the pressing demands to address climate change.

Thus, the latter opens a "pandora's box" of trade-offs and uncertainty. From a design perspective, a certain simplification and delimitation extent is necessary to create accessible content, whereas key elements might trigger greater engagement. To shed light on the effectiveness of specific features, this paper will leverage on key gamification principles.

Although empirical utilization of gamification on sustainability besets with uncertainty, existing literature, despite limited, reveals enormous potential. Xu (2011) suggested gamification can stimulate sustainability consciousness, educate citizens, and motivate pro-environmental behavior. However, gamification terminology, scope, and boundaries remain inconsistently defined. Hence, this paper will edge on one of the most well-cited definitions. Established at the intersection of industry practitioners, Deterding et al. (2011) defined gamification as "the use of game design elements in non-game contexts"(p.10).

Gamification components are numerous and diverse. Ventures to align those into formal propositions occasioned several frameworks aiming to depict game-design elements and principles (Werbach and Hunter 2012; Robson et al., 2015). Given the assorted landscape of taxonomical alternatives, for brevity purposes, this paper will leverage on the similarities amid this groundwork. To do so, it will hinge on Hamari et al (2014) categorization of the most applied motivational affordances. The authors' findings refined the famous PBL triad (points, badge, leaderboards) among the most enacted elements, and systemized these and other game-mechanics and design principles (see Appendix 1).

These principles, the formerly identified drawbacks, and the calculator's features highlighted by Coulter et al. (2007) provided the background for the methodology adopted to develop the intervention here applied. Examples of appraised functionalities include transparency, good user-experience, visual appeal, clear information, quick completion, and social comparison.

2.6 A Twofold Approach for Carbon Literacy

Appropriate knowledge and motivation to act are prerequisites for environmentally conscious actions, but not enough. Firstly, information is insufficient if promoted actions entail monetary, time, or behavioral disadvantages. Secondly, even when efficiency improvements are affordable at all dimensions, individuals can only partially influence their lifestyles (Steg & Vlek, 2009). People's choices are also predicted by existing infrastructures and prevailing services. Laakso and Lettenmeier (2016) pointed systemic changes called for adjustments in markets, infrastructures, policies, cultural norms, knowledge, and practices. Given the multitude of pro-environmental barriers, a combination of interventions would be most successful (Thøgersen, 2005).

The intervention developed aimed, therefore, to be twofold.

Firstly, as prompted by Steg and Vlek (2009), novel expertise triggers attitudes shift, that may exert certain influence but hardly activate behavior changes. Thus, to perpetrate the latter, commitment strategies' basics, framed as intentions' implementation, were leveraged, as its success in inducing behavioral change has been materialized in past research (Abrahamse et al., 2005; Lehman & Geller, 2004).

Secondly, to initiate a systemic shift to a low-carbon paradigm, identification of the hotspots where actions might be taken is critical for the stakeholders involved (e.g. consumers, governments, and businesses). Thus, beyond providing users with a two-week learning challenge, one must not set aside the importance of being attentive to the public's perspectives. Hence, collecting and analyzing information on the determinants of environmental behaviors, including user's lifestyles, attitudes, personal capabilities, and contextual forces, provides invaluable data for academia, policymakers, and even companies, to enable those steps lessening personal emissions to be taken.

To conclude, this paper attempts to bridge existing practice and mitigation gaps by presenting the methodology and framework adopted to design a two-week gamified carbon challenge. It aims to move citizens out of their carbon-intensive comfort zones while gathering critical information on major lifestyles' drivers.

These objectives directed the formulation of the subsequent hypotheses:

H1a: A gap exists between actions' perceived efficacy and engagement frequency.

H1b: The gap size differs among behavioral sub-categories.

H2a: Different consumption domains show significant differences in carbon literacy, carbon footprint, and barriers to pro-environmental behavior.

H2b: Carbon footprint is negatively associated with carbon literacy and positively associated with barriers to pro-environmental lifestyles.

H3a: Participants increase carbon literacy levels upon intervention participation.

H3b: The intervention spurs action-intention.

H3c: Changes in literacy are associated with perceptions of the intervention as an engaging and fun experience.

3 Research Methodology

The following section discloses the research methodology employed, the data collection strategy, and the instruments selected for effects' measurement.

As previously clarified, the aim of this research was not to simply record the relationship between gamified-systems and pro-environmental behavior change. Rather, its utmost purpose was to fathom out whereby interventions, like the one appraised hereupon, may contribute towards the structure of knowledge, abilities, and motivations that preside over habits giving rise to carbon emissions. To attain the set objective, the research developed a gamified survey tool as the primary learning and data collection instrument.

3.1 Research Setting: The Carbon Footprint Movement

3.1.1 Research Structure

The intervention was foremost designed as an informational strategy. Its "holy grail" was to heighten user's knowledge on sustainability issues, environmental impacts of personal behaviors (carbon footprint), and ultimately raise awareness on available alternatives and respective effects (carbon literacy).

TCFM targeted carbon literacy and footprint reduction in several ways.

Firstly, upon reflection of the trade-offs reviewed in the literature, usability prevailed over complexity. Instead of exact results, a simplified bottom-up method was applied, retrieving adjusted yearly footprint figures based on preferences and entry data (Figure 1). The goal was to familiarize users with the topic and spur meaningful action rather than provide exact captures. The calculations performed were sourced from an open-source carbon calculator (Appendix 4). Citizens were informed results represented only ballpark estimates.

Secondly, results and conceptualizations were demystified, and feedback was given to help players puzzle out what drives emissions. On top of that, actionable knowledge was provided along with tailored recommendations. To do so, an action plan was crafted, empowering users with the ability to customize the convenience and skill level of their own paths for carbon-saving actions.

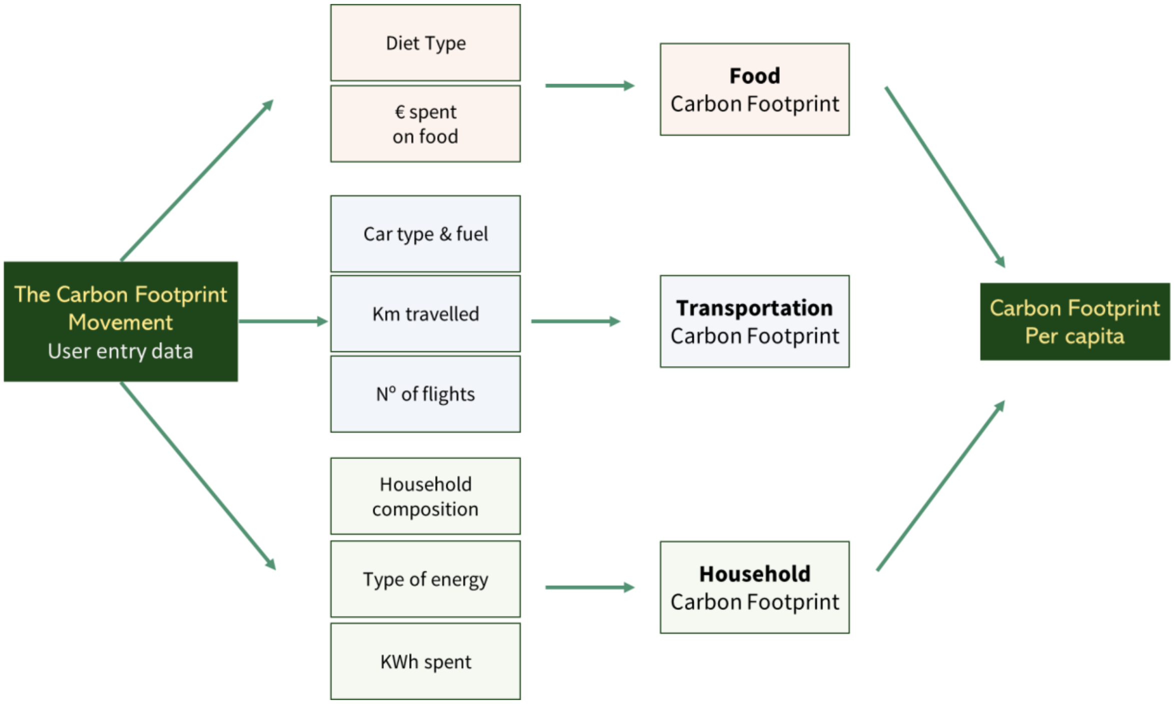


Figure 1 TCFM carbon calculator diagram

Lastly, aligned with previous research on calculators, the intervention was divided into distinct categories. Those were analogous to the dominant consumption domains, from the standpoint of environmental impacts. Therefore, the movement assigned carbon-generating activities into three sections: Food, Mobility, and Household related-emissions. Carbon footprint scores, along with feedback, and action-taking suggestions were split among these categories unfolding, at last, dimensions' relative significance.

TCFM was ergo executed in three phases. At first, baseline measurements were collected, five days ahead of the movement kick-off. Subsequently, the two-week challenge was carried and subdivided into the three mentioned domains. At the close, a follow-up measurement was included.

The former stages and premises were set up under the format of a gamified-survey tool, engendered through the combination of an online survey software (Qualtrics) and a Conversational User-Interface platform (Landbot). The underlying purpose was to forge these instruments and launch a user-centered fun experience, as fun often prompts engagement and, consequently, cognitive absorption. Thus, TCFM essence builds upon gamification principles. Further discussed parameters, including calculators' best practices and current pitfalls, were also on the basis of the movement blueprint.

3.1.2 Research Design: Application of gamification

Gamification is an umbrella conception, inconsistently defined or applied. Despite its blurred scope and boundaries, at the intersection of the different conceptualizations, two key ingredients emerge. Firstly, an enjoyment component becomes key for effective motivation and engagement. Secondly, the former can be accomplished through game-thinking and game elements, comprising principles, patterns, and methods inspired by games.

Conceived to introduce carbon concepts and personal impacts, to be and remain attractive, the system applied game-design principles and elements. To illustrate the former, a user-journey semblance is disclosed hereupon.

The movement was designed to be fun and lighthearted, with uncluttered graphics and creative layout, while being quick-to-complete and ubiquitously providing personalized feedback. Each juncture opening comprised a lively rapid interaction with the so-called "CarbonBot", a conversational interface that escorted the player throughout each encounter. Bearing the resemblance of an informal concierge, the conversation was casual and pleasant, directions and expectations were set forward, and finally, feedback and behavior reinforcement were applied.

Without further ado, users were directly ushered to the Qualtrics survey. Both tools aimed at producing a design that evokes a pleasant visual sensation. Framed like quests, to complete each theme-edition, players had to surpass a set of micro-games. These burst-out different interactions with subjects, through which questions were answered and data collected. For each edition, sporadic segments exhibit graphical appearances sketched to purposefully remind well-known games (defined from Amazon's Best Sellers), users were likely to be familiar with and associate with joyful moments. Moreover, the layout chosen was often compatible with the general theme for that specific edition. Take the example of the household edition a section of cross-questions was modeled to extract the ludic qualities of the illustrious monopoly board game.

Beforehand, players built their profiles, a username was settled, and personalization was carried along the whole challenge. Following the onboarding, the narrative became consonant among editions and arranged around a few leading milestones (see Appendix 3).

To complete each series, players started by quickly gauging their literacy. Then, and through the minimal detail level, users arrived at a reasonable annual carbon footprint estimation on that specific domain. A trivia theme-based moment followed, whereby participants were awarded points for correct answers. Having completed that, one was forwarded to an extra micro-game. The latter was once again strategically sketched to mimic playful scenarios. These were decorated to bear the resemblance of in-fashion card games (Amazon’s Best Card Games Sellers e.g. Cards Against Humanity) to produce the intended aesthetic of sensation: simple and plain fun.

Finally, a pledge section was presented, allowing users to build customized scenarios for footprint reductions. Users were given a ‘handbook’ of hypothetical behavioral changes and general estimates of its reduction potentials. Lined-up to roughly cover a comprehensive suite of lifestyle choices while enabling dissimilar effort levels, the pledge function empowered players to delineate their own convenient pathways for a greener living. Following the interval range established by Wynes and Nicholas (2017) for emissions’ reductions, actions were theme-based and further classified into high-impact (saving$>0.8tCO_2$), moderate-impact (saving $0.2<tCO_2<0.8$) and low-impact (saving$<0.2tCO_2$).

Additionally, the pledges’ list also provided participants the chance of collecting badges, signaling, and rewarding different achievement levels. In consonance with the pledges, these visual icons signifying recognition were drafted accordingly (Figure 2).

Figure 2 TCFM badges examples

Furthermore, as pointed by Whitmarsh (2009b), individual actions are embedded within social settings. Hence, social norms and moral obligation senses influence behaviors. Accordingly, to bring a sense of citizenship and social dynamics into the movement, upon each edition, the ability to benchmark one's footprint with the performance of others, global averages, and reduction targets, was extended. Plotted as a motivational feedback system, a leaderboard displayed participants' ranking status, settling a context for results, and prompting recognition (Figure 3). This social positioning was resorted to incite competitiveness and symbolize achievement.

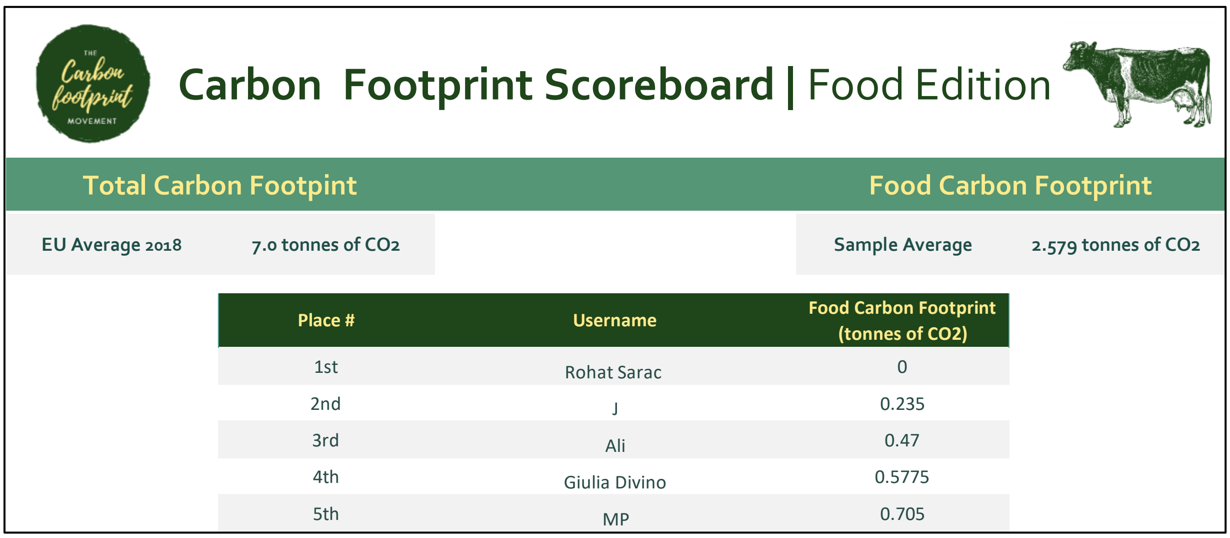


Figure 3 Example of carbon footprint leaderboard output (Food Edition)

Feedback systems were immediate and frequent and predominately implemented as a form of behavior reinforcement. For every achievement, descriptive normative information often coupled with injunctive messages was drawn-out. Apart from points and badges, this game-element was often enacted through gifs and emoticons.

At last, the challenge also regularly rendered helpful official-sourced tips, tricks, and incentives for environmentally friendly behavior (Appendix 2). These were often tailored to user's results and data input. Other engaging elements were included in the gamification loop: good user-experience, specific goals, continued interaction, supporting information, and interactive learning.

To sum up, the movement was designed to engage and educate people on solutions to sustainability issues. To do so, it laid upon four cornerstones: demystify carbon footprint, supply enjoyment, distribute relevant information, and reward informed action.

3.2 Primary Data

3.2.1 Data Collection

Subjects were invited to participate via anonymous links shared within different channels: E-mail, Facebook, Instagram, and WhatsApp.

Prior to the start, the bot briefed players on procedures and study aims. They were informed participation was voluntary, and data would be anonymized. At last, participants were asked to consent the public disclosure of carbon footprints and further instructed to adopt a username to assure anonymity on the latter.

The surveys (Appendix 3) adopted a sequent logic, so participants progressed smoothly among matters. Closed and open-ended questions were concurrently leveraged. The former provided concrete responses, while the latter aimed at opinion gathering while eliciting spontaneity.

Overall, four leading primary data categories were gathered from participants: sociodemographic characteristics, carbon literacy measurements, pro-environmental behavior estimations, and carbon footprint sizes. Additional data on environmental attitudes and values were collected. Data gathering was parallel to the three previously depicted phases of TCFM: pre-challenge (T1), challenge, and post-challenge (T4) data collection. Hereupon, these constructs, and respective measures applied to capture them, are described.

3.2.2 Instruments

<u>Pre-series Measures</u>

Demographic. Including gender, age, education level, nationality, income.

Pro-environmental values and attitudes. Meant to further characterize users, these were derived from a battery of 10 statements to which participants were inquired on how much they agree on a 5-point Likert scale, ranging from “strongly disagree” to “strongly agree”. *Pro-environmental attitudes* were derived from the Special Eurobarometer 468 (European Commission, 2019) and DEFRA (2008). *Environmental values or worldviews* were assessed using the “New Environmental Paradigm” (NEP) shortened version scale conceived by Dunlap et al. (2000). The former was deployed as it is well-validated and widely applied in pro-environmental behavior research (Hawcroft & Milfont, 2010; Dunlap 2008).

General environmental concerns. Following Boyes and Stanisstreet's (2012) work, this section was conceived to probe player's overall environmental concern levels (1="I'm not worried at all", 4="I'm very worried").

Pro-environmental behavior (PEB). Respondents were asked how frequently they performed a basket of pro-environmental behaviors. Behavior frequency was captured through a 4-point Likert scale ranging from "never" to "always". The action list was compiled primarily based on a DEFRA Tracker Survey (Thornton, 2009). Behaviors were drawn to cover carbon-generating activities emerging from the three addressed domains: Food, Mobility, and Household. The seven components encompassed: "Avoid meat-eating", "Buy local, seasonal foods", "Use car less", "Take fewer leisure flights", "Recycle", "Save water" and "Save energy".

Perceptions of behaviors. Prior to rating behavior frequencies, participants indicated their perceptions of the environmental impacts of the above-presented items. Available answers encompassed "would make no difference", "small impact", "medium impact", and "major impact".

Pre and post-series measures

These cognitions were generally devised. Pre-series and post-series measures were run-up to spot for short-term effects resulting from the intervention.

Carbon literacy. Literacy was subdivided into its three comprising elements: *knowledge*, *skills*, and *motivation* (Whitmarsh et al., 2009). As no corresponding model has been engendered so far on the pro-environmental field to operationalize carbon literacy, a six-question set was developed. Constructs were assembled following the most recent definition of the term postulated by Howell (2018). Accordingly, the *knowledge* constituent appraised three components: basic notions, understanding of carbon emissions' causes and consequences, as these relate to daily actions, and lastly, appreciation of its relative impacts. *Ability* aimed at disclosing participants' aptness to obtain and evaluate relevant information. *Motivation* targeted one's willingness and action-intention to reduce emissions.

During-series measures

The following constructs were specifically devised and repeatedly collected for each theme-based challenge.

Carbon Literacy. A shortened version of this construct was additionally collected, to scrutinize variances among consumption domains (food, mobility, household).

Carbon Footprint (CF). Each interplay retrieved a rough footprint yearly estimation in CO2 tonnes on that domain. A bottom-up simplified approach was applied, presenting users with results based on one's diet, traveling habits, and domestic energy usage (see Appendix 4 for calculation details).

Perceived Barriers. This measure elaborated on the individual and structural barriers of dissonance and denial of lower-carbon lifestyles. Barriers set was selected based on literature prevalence.

Action-Intent measures. Following each intervention, participants were presented with the option to pledge changes from a wide spectrum of behaviors. Based on literature prevalence, the action set was strategically chosen to comprise multiple domains, impacts, and frequencies (Stern, 2000).

Additional questions.

The final questionnaire included evaluation inquiries concerning the intervention itself. An open-ended question invited users to freely share their opinions on the movement. Appendix 5 displays a list summarizing all instruments included in the questionnaires.

3.3 Data Analysis

The lion's share of collected data can be classified into primary categorical data, ordinal (e.g. agreement level), and nominal (e.g. gender). To explore and interpret results, statistical analysis was performed and predominantly operationalized under RStudio.

Before bursting out to test the hypotheses, certain variables were further adapted to ensure items were comparable. Numerical codes were ascribed to non-numerical items, and negatively framed queries were reverse-coded. The database was screened for outliers and data input accuracy, mostly through scatter plots' visual inspection.

Following the corrections, descriptive and frequency statistics were conducted.

Lastly, normality testing was run for most variables, leveraging the Kolmogorov-Smirnov test. Subsequently, either paired t-tests or Wilcoxon-Signed-ranks tests were carried to appraise carbon literacy differences among prime consumption dimensions, and to single out significant differences among baseline and repeated literacy components.

Correlation tests were executed to seize associations between carbon literacy and carbon footprint. Given most variables included were not normally distributed, non-parametric tests were most appropriate. Thus, Kendall's tau statistical test was generally applied (Field, 2015). Finally, to assess further relationships among variables, this paper resorted to complementary bivariate correlations and, ultimately, to multiple regression analysis.

4 Findings

The following section reports and sequentially discusses the obtained results. The previously laid out hypotheses are tested, and research questions are answered.

4.1 Results

4.1.1 Primary Findings

A total of 147 people responded to the first questionnaire. However, only 93 people fully engaged in all phases comprising TCFM. Consequently, the final sample accounted for 93 respondents, and details of their sociodemographic profiles are displayed in Appendix 6. Females comprised 47%, and nearly three-quarters of the cohort were educated to a degree level or beyond. Nationality-wise, the sample was highly diverse, albeit Portuguese respondents (65%) were strongly overrepresented. The lion's share of respondents ages ranged from 18 to 35 years. Nearly 80% expressed concern about the climate, whilst only a minority (11%) admitted having previously calculated their CF.

Reported frequencies of pro-environmental actions are displayed in Appendix 7. The average score was 2.59, meaning the average participant engages in pro-environmental behaviors more than sometimes (2) but less than often (3).

While 52% reported to "always" recycle, only 8% avoided meat-eating. Moreover, our sample exhibited a wide reluctance to change traveling habits. Despite such resistance, "using car-less" was simultaneously the most mentioned "highly effective" mitigation action. Such disparity between willingness to carry an option and its believed usefulness brings the value-action gap concept and ushers in the first hypothesis.

4.1.2 The Value-Action Gap

Individuals often conveyed strong environmental beliefs, but concurrently frequently failed to follow through with those attitudes.

Various results pointed out a value-action gap among the entire sample at T1.

At first sight, the gap is conjectured as respondents displayed stronger environmental beliefs contrasting with less perpetrated behaviors. On average terms, 46.6% believed pro-environmental behaviors to have a "major impact" in climate change mitigation, whereas only 20.6% reported to "always" enact that same action set.

As Kolmogorov-Smirnov tests confirmed normal distributions for both variables (p-values>.05), paired t-tests were leveraged, indicating significant differences between the mean score of values (3.25) and actions (2.59) ($t(146)=-15.189$, p-value=.000), fully corroborating H1a. A further gap assessment was taken by gauging correlations. As expected, only weak correlation (n=147, $\tau=.294$, p-value=.000) was found among the PEB's believed usefulness and its adoption frequency.

Moreover, as theorized, the gap size differed among behavioral sub-categories, validating H1b. Based on Kendall's tau correlations, it was widely settled the relationship among action efficacy and action engagement was relatively weak for the majority of behaviors displayed (Appendix 10). The gap was further pronounced among specific items, as no relationship appeared to exist between recycling (n=147, $\tau=.002$, p-value=.975) or car usage (n=147, $\tau=.062$, p-value=.420) and respective efficacies. However, one headline behavior diverged from this tendency, as one's disposition to avoid meat-consumption seemed to increase fairly with its perceived effectiveness in tackling climate change (n=147, $\tau=.402$ p-value=.000).

To sum up, the efficacy beliefs of PEBs moves in tandem with its adoption frequency. However, while these variables tend to rise in response to one another, this relationship emerged as a predominantly weak one. Meaning, as foreseen by the value-action gap, stronger environmental beliefs might not relate to more frequent pro-environmental actions. The former results from the assortment of factors (e.g. background and attitudinal variables) constraining human behavior. Perceived effectiveness of behaviors is only one of the inputs influencing its adoption. Therefore, to assess the relative significance of different variables, multiple linear regression analysis was further administered.

Firstly, analysis was performed on the complete PEB set. The former was regressed on sociodemographic variables (education, age, gender, income), attitudinal items (NEP, concern, and attitudes), carbon literacy constructs, and PEB's perceived effectiveness. The model explained 28.4% of the variation in pro-environmental behavior (R2=.284). As shown in Appendix 11, knowledge (measured by literacy), pro-environmental attitudes and worldview are weak predictors of PEB's frequency. Concern and efficacy beliefs, on the other hand, appear to be better predictors of the broad PEB set.

Given the established divergence among PEBs' engagement, regression analyses were further realized for each behavioral cluster, regressed on comparable variables. Results (aggregated in Appendix 11) were consistent with previous findings. Firstly, the variance proportion unraveled by this specific model was positively atypical among the "eat less meat" action ($R2=.338$). Moreover, the frequency of eating less meat significantly increased with the option's perceived effectiveness. On the extreme opposite, the same independent variables set appeared to explain only about 10% of the variation amidst recycling and car avoidance frequency, highlighting the value-action gap. For actions including saving water and energy, or taking fewer flights, less than 17% of the variance was explained by the model.

To conclude, beyond settling a value-action gap among the sample, supporting H1a, these results also demonstrated its size differed among behavioral sub-categories, confirming H1b.

4.1.3 Carbon Literacy, Carbon Footprint, and Barriers to Pro-environmental Behavior

<u>Differences between domains</u>

Starting with carbon literacy, its elements were individually appraised per consumption segment. Mean scores revealed carbon-related knowledge levels to be greatest among food-generating activities, whereas ability and motivation reported the highest scores across the domestic-energy domain (Table 1).

This dissertation started by determining how carbon-literate individuals were. The distributions of literacy components, per consumption cluster, were assessed for normality using the Kolmogorov-Smirnov-normality test.

As most variables were not normally distributed, related-sample Wilcoxon-signed-rank tests were leveraged, to bring to light differences in carbon literacy across domains.

Table 1 Descriptive statistics and normality testing for domain-specific carbon literacy (N=93)

	Domain	Mean	S.D.	Min.	Max.	K-S normality test p-value
Knowledge	Food	**3.38**	0.66	1.33	4.67	0.00
	Mobility	2.71	0.98	1.00	5.00	0.00
	Household	3.26	0.82	1.00	5.00	0.00
Motivation	Food	3.58	1.02	1.00	5.00	0.00
	Mobility	3.77	1.14	1.00	5.00	0.00
	Household	**4.33**	0.73	2.00	5.00	0.00
Ability	Food	3.23	0.97	1.00	5.00	0.00
	Mobility	3.43	1.12	1.00	5.00	0.00
	Household	**3.67**	0.71	2.00	5.00	0.00
Literacy	Food	3.58	1.02	1.00	5.00	0.04
	Mobility	3.30	0.73	1.67	4.67	0.18***
	Household	**3.75**	0.53	2.33	5.00	0.07***

***If p>0.05, we believe variable follows a normal distribution

Firstly, significant vicissitudes across consumption clusters were found on knowledge to reduce emissions pertaining to one's daily activities (p-values<.01). These results put forward significantly higher dietary carbon-cognizance, juxtaposed with significantly lower levels for personal transportation. Secondly, differences between ability to mitigate CFs were only statistically significant between domestic and food-related emissions (Z=3.450, p-value=.000), emphasizing higher aptness to reduce domestic energy-related emissions with a moderate effect size (r=.358). The former propensity was coupled with appreciable motivation. One's motivation to reduce carbon discharges was significantly higher for home-related activities when contrasted with motivation to mitigate travel (Z=-3.905, p-value=.000) and dietary (Z=-5.741, p-value=.000) carbon releases, with respectively moderate and large effect sizes (r=.405, r=.6). No significant differences were found across motivation to adopt pro-environmental travel and food consumption patterns (Z=1.874, p-value=.07). These results validate the initial portion of H2a.

Secondly, it was concurrently conjectured the consumption segments considered contributed differently to one's impact. To draw adequate conclusions, a thorough CF inspection was carried, and a similar analysis was conducted.

Based on the previously drawn calculation methodology, CF estimations were derived. Measured in CO2 tonnes, footprints ranged from 1.57 to 25.18, with a reported mean of 7.68 CO2 tonnes. A detailed CF breakdown per emissions' source and the respective basic statistics were summarized in Table 2.

Table 2 Descriptive statistics and normality testing for domain-specific carbon footprints (N=93)

		Mean	%	S.D.	Min.	Max.	K-S normality test p-value
Food		**2.58**	**33.6%**	1.83	0.24	9.63	0.00
Mobility	Road	1.49	19.4%	2.37	0.00	14.04	0.00
	Air	2.33	30.4%	3.55	0.00	18.21	0.00
	Total	**3.82**	**49.7%**	4.24	0.00	21.18	0.00
Household		1.28	**16.7%**	0.79	0.05	4.83	0.07***
Total		7.68	100%	5.32	1.57	25.18	0.00***

***If p>0.05, we believe variable follows a normal distribution

To conduct a proper contribution analysis, non-parametric tests were adopted, as nearly all variables here appraised displayed non-normal distributions. Related-samples Wilcoxon-Signed-ranks tests pinpointed significant differences among all-three areas, namely between mobility and food CF (Z=2.341, p-value=.019), with a small effect size (r=.243), and home and food CF (Z=-6.451, p-value=.000), with a large effect size (r=.669).

These findings validate the portion of H2a claiming CF to differ among domains, and highlight transportation (49.7%), followed by food consumption (33.6%), as the processes contributing the most to one's environmental impact. Within mobility, air travel embodies a significant fraction, representing roughly 61% of transportation footprints per capita.

Thirdly, as ascertaining the potential for lower-carbon lifestyles requires a deep understanding of the elements constraining behavioral goals, Table 3 summarizes perceived barriers per cluster. Consistent with Lorenzoni et al. (2007), barriers were categorized into individual and social to outline internal and external constraints' dissimilarities.

Clusters' differences speak for themselves. Internal-wise, low prioritization compared to other issues was mostly present among dietary-related choices. Convenience reasons were mainly felt among transportation options, whereas reluctance to change lifestyles limited mainly household mitigation actions. External limits were mostly curbing pro-environmental dietary and mobility choices. The most prevalent inhibitor was lack of enabling mobility initiatives (58%).

Financial constraints and lack of locally accessible information were mentioned respectively by 33.3% and 44.1% among the food-consumption segment.

Table 3 Barriers to climate change engagement (N=93)

	Food	Mobility	Household
Internal(Individual)			
Lack of knowledge	6.5%	7.5%	18.3%
Convenience constraints	12.9%	**48.4%**	6.5%
Habitual behavior/apathy towards change	9.7%	26.9%	**34.4%**
Other issues are of greater importance	**30.1%**	4.3%	11.8%
Skepticism/Disempowerment	4.3%	1.1%	2.2%
External(Social)			
Financial constraints	**33.3%**	10.8%	11.8%
Lack of info availability	**44.1%**	7.5%	16.1%
Lack of enabling initiatives/infrastructures	20.4%	**58.1%**	20.4%
Mean	1.61	1.65	1.22
S.D.	1.12	0.99	0.75
Min.	0.00	0.00	0.00
Max.	4.00	5.00	4.00
K-S normality test p-value	0.00	0.00	0.00

***If p>0.05, we believe variable follows a normal distribution

Lastly, to cease the analysis on H2a, related-samples Wilcoxon-Signed-ranks tests were further applied. Significant differences were found among the mean score for house-related barriers and the constraints on the other two domains. Perceived inhibitors to pro-environmental behavior were therefore significantly inflated among the most environmentally impactful domains (food and house: Z=2.820, p-value=.005, r=.292; mobility and house: Z=3.861, p-value=.000, r=.400), confirming the last section of H2a.

These results indicated different consumption domains showed significant differences in carbon literacy, carbon footprint, and barriers to pro-environmental behavior, validating H2a.

<u>A Correlational Analysis</u>

Converging towards the last portion of the research question in point, Kendall's tau correlation was used to assess relationships among variables.

No significant correlations between household-related CFs and literacy constituents, at this specific domain, were found. In contrast, food and transportation CFs were significantly negatively correlated with the respective domain-specific literacy levels (n=93, τ=-.215, p-value=.005 and τ=-

.169, p-value=.023, respectively). Extensive analysis unveiled significant correlations with the former footprints pertaining only to the ability and motivation literacy dimensions, at both consumption categories. Despite weak associations, these findings suggest those who perceived themselves as more able and motivated to mitigate food and transportation-related emissions, were more likely to disclose lower CFs at those domains. (Appendix 13).

To wrap up, this paper went further into claiming domain-specific CFs sizes to be associated with barriers to pro-environmental behavior. At first sight, no associations emerged among generalized constructs. In-depth analysis of the broadly mentioned barriers revealed novel insights among the most impactful domains (food and transportation). Higher segmented CFs were significantly positively associated with the most recurrent barriers in those domains. In particular, those perceiving public transportation inefficiencies were more likely to have higher mobility-related CFs ($n=93$, $\tau=.294$, p-value=.000). Similarly, respondents claiming food-related emissions as a low-priority issue were more likely to display higher food-related footprints ($n=93$, $\tau=.177$, p-value=.042).

All in all, results only partially validate H2b. Meaning, carbon footprint was negatively associated with carbon literacy but only positively associated with the most frequently mentioned barriers. Additionally, these associations were exclusive to the food and transportation consumption domains.

4.1.4 The Outcomes of the Intervention

This dissertation sought predominantly to ascertain whether participants increased carbon literacy levels over the course of the intervention. Change in literacy was measured by comparing literacy constructs' data from pre-intervention (T1) to immediately post-intervention (T4).

Figure 4 plots carbon literacy scores at T1 against its corresponding values at T4. For cases moving along the diagonal line, literacy scores remain unchanged. In cases above the line, carbon literacy increased, while those below the line reported measurement decreases. Inspection of the plot pointed out a general positive trend, suggesting carbon literacy levels increased for the majority of participants, between T1 and T4.

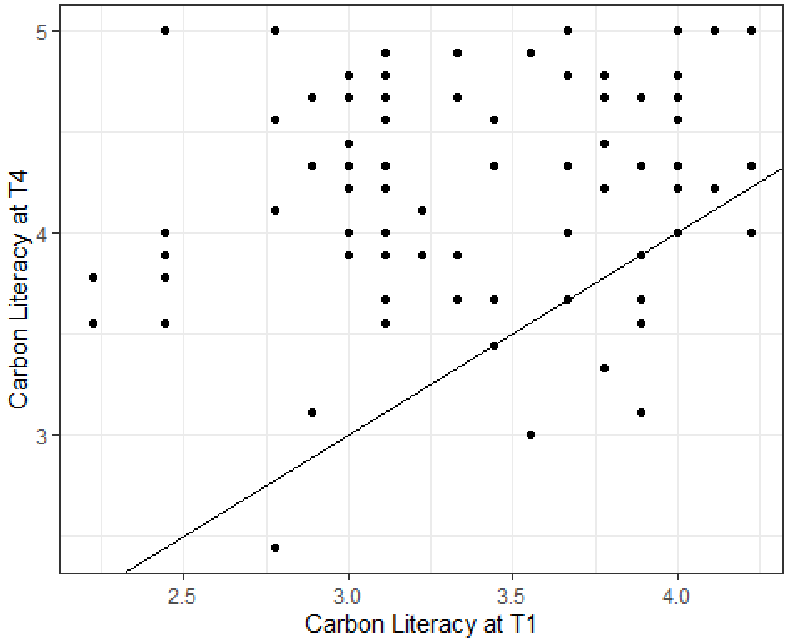


Figure 4 Change in carbon literacy between T1 and T4

The mean carbon literacy score at T1 was 3.42 and at T4 was 4.21.

The distributions for literacy dimensions were assessed for normality at both points in time, using the Kolmogorov-Smirnov-normality test. The knowledge factor showed a normal distribution at T1, but not at T4. Motivation and ability were not normally distributed at all times. The all-embracing carbon literacy instrument was normally distributed at T1 and T4. Descriptive statistics and normality testing results are presented in Table 4.

Paired-sample t-tests indicated significant differences between T1 and T4 scores for the all-inclusive literacy measure (t(92)=-11.513, p =.000). Related-samples Wilcoxon Signed-ranks tests indicated statistically significant differences between T1 and T4 scores for all three components: knowledge (Z=-5.256, p-value=.000), with a moderate-to-large effect size (r=.545), motivation (Z=-7.835, p-value=.000) with a large effect size (r=.812) and ability (Z=-2.992, p-value=.003) with a moderate effect size (r=.31).

Table 4 Descriptive statistics and normality testing for carbon literacy at T1 and T4 (N=93)

	Time	Mean	S.D.	Min.	Max.	Increase	K-S normality test p-value
Knowledge	T1	3.23	0.71	1.33	5.00	15.6%	0.05***
	T4	3.73	0.70	1.67	5.00		0.04
Motivation	T1	2.95	0.99	1.00	5.00	**51.5%**	0.00
	T4	4.46	0.67	3.00	5.00		0.00
Ability	T1	4.09	0.89	1.00	5.00	8.4%	0.00
	T4	4.43	0.67	2.00	5.00		0.00
Literacy	T1	3.42	0.52	2.22	4.22	**23.0%**	0.07***
	T4	4.21	0.54	2.56	5.00		0.25***

***If p>0.05, we believe variable follows a normal distribution

These figures suggested significant increases in carbon literacy levels of 23%, from before to immediately after taking part in TCFM, fully supporting H3a. The former was derived from significant rises among one's knowledge (15.6%) and ability (8.9%). However, crucial is to remark literacy inflations to be utmost driven by significant enhancements in users' motivation to reduce one's CF (51.5%).

So far, statistical testing unveiled significant changes amid literacy. Hereupon, bivariate correlation was applied to ascertain relationships among the different literacy elements (Appendix 14). Knowledge was positively correlated with the remaining literacy factors at T1, but only weakly. Whereas no significant correlations were found among ability and motivation ahead of the intervention. At T4, all three constructs exhibited significant positive and stronger correlations amidst one another. The positive correlations between knowledge, motivation, and ability suggested a relationship between higher understanding, greater motivation, and soaring ability, upon program partaking. The associations were most pronounced among knowledge and ability ($n=93$, $\tau=.470$, $p=.000$). The remarkable correlations' improvement implied literacy dimensions to better align after one has taken part in TCFM.

Secondly, this section was also keen on inferring whether the intervention fostered action-intention and under which domains were participants most and least inclined to uptake sustainable alternatives. Pledges were used as a proxy for intent-oriented action. Ranging from a low of 0 to a high of 14, with a mean of 5.6 pledges, Kolmogorov-Smirnov-normality tests revealed average pledges per participant to be normally distributed, except when appraised for the specific consumption domains (p-values<.05).

Thus, related-samples Wilcoxon-Signed-ranks tests were applied, indicating significant differences between house and mobility-related pledges (Z=6.109, p-value=.000), with a large effect size (r=.633), and between house and food-related pledges (Z=4.955, p-value=.000), with a moderate-to-large effect size (r=.514). The difference between food and mobility pledges was not significant (Z=1.486, p-value=.137). Appendix 16 illustrates the former, revealing participants were mostly disposed to engage in actions to mitigate domestic energy use (46% of total pledges). Whereas smaller sample proportions were willing to opt for dietary (29%) and transportation (25%) behavioral changes.

Nonetheless, these results support H3b, meaning the intervention spurred action-intention overall.

Lastly, TCFM was regarded as an entertaining didactic experience. Based on participants' responses to the question "What do you think about TCFM?", a frequency-based word cloud was assembled (Figure 4). Accordingly, the prevailing concepts used by respondents to describe one's exposure were *informative*, *fun*, *engaging,* and *awareness*. Further viewpoints encompassed outlooks on the *appealing* design, *innovative* and *encouraging* approach, and *useful* content.

Figure 5 Frequency-based word cloud on "What do you think about TCFM?"

Moreover, Kendall's tau correlations were leveraged, to appraise whether one's verdict on the intervention was associated with carbon literacy out-turns. This analysis unveiled a significant positive correlation (n=93, τ=.235, p-value=.007) between entertainment perceptions and changes in carbon literacy, suggesting literacy increases aligned better with fun and engaging interventions, fully validating H3c.

4.1.5 Additional Tests

Further statistical analyses were conducted to provide additional, more detailed insights about participants and the intervention.

Socio-demographics: a correlational analysis

The analysis was firstly conducted to assess whether carbon literacy, carbon footprint, and barriers measurements were related to any of the demographic variables collected.

Overall, clustered literacy levels reported no significant correlations with socio-demographic characteristics, despite few exceptions. Mobility and dietary literacy levels were significantly negatively correlated with Portuguese nationality ($n=93$, $\tau=-.238$, $\tau=-.208$, respectively, p-values$<.02$). Note, Portuguese was anchored as the outlining nationality for analysis performance, given its sample predominance. Secondly, food-related literacy, namely motivation, was associated with gender, indicating female participants were more likely to display higher awareness and motivation to reduce dietary emissions ($n=93$, $\tau=.325$, p-value$=.000$). Perhaps crucially is to also account for the significant positive association among female gender and pro-environmental attitudes ($n=93$, $\tau=.218$, p-value$=.014$).

Furthermore, CFs' size and composition associations with socio-demographic characteristics were mapped out. Significant positive correlations between income and footprint, for the food ($n=93$, $\tau=.168$, p-value$=.026$) and mobility ($n=93$, $\tau=.150$, p-value$=.044$) domains, suggested increased affluence to be associated with higher CFs at those consumption spheres. Additionally, whereas females were more likely to display lower food CFs ($n=93$, $\tau=-.327$, p-value$=.000$), significant positive correlations pointed out associations between Portuguese participants and higher mobility CFs ($n=93$, $\tau=.310$, p-value$=.000$). (Appendix 12)

Barriers perceived to voluntary environmentalism were not significantly correlated with any socio-demographic characteristics.

At last, carbon literacy changes between T1 and T4 were not significantly correlated with any of the demographic measures collected (Appendix 15). Only positive correlation between motivation changes and baseline environmental attitudes ($n=93$, $\tau=.211$, $p=.009$) and values ($n=93$, $\tau=.239$, $p=.003$) was gauged.

Action-intention and baseline carbon literacy: a correlational analysis

Appendix 16 congregates a set of descriptive insights, namely participants' readiness to undertake environmentally responsible actions, in particular low-to-moderate impact actions. Concerning food consumption, 59% pledged to waste less food, and nearly half the sample professed willingness to eat local, in-season food. In contrast, high-impact actions, namely reduce meat-intake, were generally rejected (22%). A resembled trend was perceived regarding personal transportation: the public was more willing to shift towards a fuel-efficient driving (50%) than to take fewer flights or live car-free (14%). When it comes to energy consumption, 4 out of 5 recommendations comprised only low-to-moderate impactful actions, thereafter, as theorized, higher sample proportions were prepared to undertake changes.

These differences across consumption areas resembled the homologous variances previously drawn for carbon literacy and footprint. Kendall's tau correlation inspection showed positive significant correlations only among action-intention and carbon literacy at all domains ($n=93$, food: $\tau=.175$, p-value=.033; mobility: $\tau=.187$, p-value=.023; household: $\tau=.281$, p-value=.000), suggesting those who were more confident of their knowledge, ability, and motivation to reduce emissions, professed greater intentions to implement corresponding recommendations. (Appendix 17). As expected by now, female gender and action-intention were significantly positively correlated ($n=93$, $\tau=.183$ p-value=.041).

Outcomes of the intervention: differences between groups

Finally, comparisons of the surveys' outcomes among the three prevailing nationality groups, Portuguese, Italian, and German, were performed using t-tests. Results in Table 5 demonstrated German participants reported significantly higher improvements in literacy levels, compared with the Portuguese and Italian users (p-values<.05). No significant differences between changes in carbon literacy were found among the Portuguese and Italian user-groups.

Table 5 TCFM outcomes: differences between user-groups

	Nationality	Mean	S.D.	t-test(p-value) *(Portuguese-Italian)*	t-test(p-value) *(Italian-German)*	t-test(p-value) *(German-Portuguese)*
Change in Literacy	Portuguese	0.709	0.643	-0.619(0.540)		
	Italian	0.807	0.585		-2.567(**0.019**)	
	German	**1.319**	0.418			3.602(**0.004**)
Actions Pledged	Portuguese	4.900	2.827	-2.452(**0.022**)		
	Italian	**7.158**	3.686		0.672(0.509)	
	German	6.375	2.264			1.677(0.124)

Lastly, post-hoc comparisons among nationalities indicated mean scores for actions pledged were only significantly different between the Portuguese and the Italian user-groups (t(18)=-2.452, p-value=.022), unveiling a higher likelihood to dismiss recommended actions among the Portuguese section. Figure 5 demonstrated the willingness to change behaviors upon the intervention was highest among the Italian (7.158 pledges/capita) and German (6.375) user-groups.

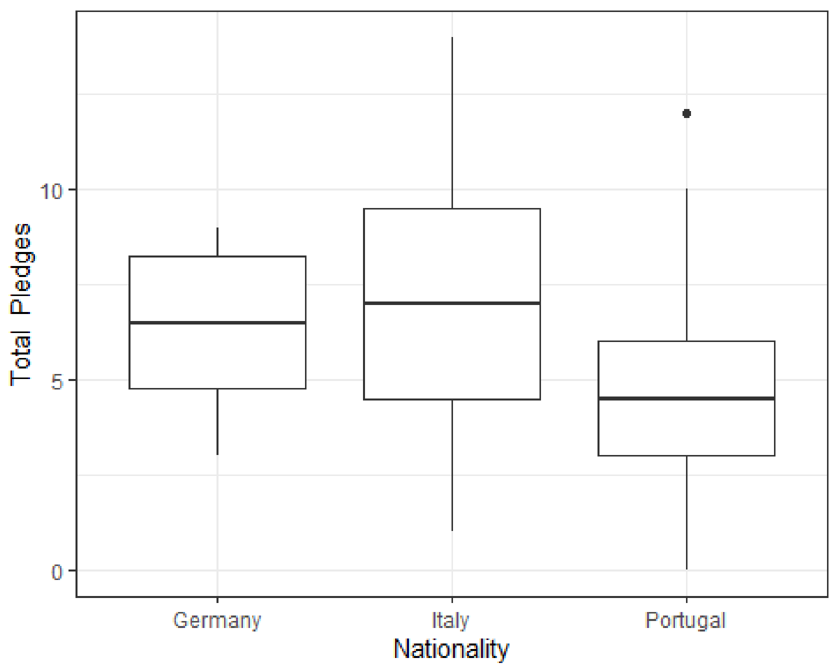


Figure 6 Action-intention per nationality

4.2 Discussion

This dissertation's overarching purpose was to provide valuable insights into the formulation of a gamification process to motivate carbon literacy enhancements. The analysis carried through set out to address three research questions, thereby testing the corresponding hypotheses.

Firstly, consistently with Whitmarsh et al. (2011), the surveys unveiled prevailing impairments in visualizing the contribution of different activities towards climate change. GHG emissions were seldom associated with one's lifestyle. Participants resembled the elsewhere reported trend on the limited knowledge concerning emissions and potential savings related to behavioral choices (Whitmarsh et al., 2009). In particular, whereas the efficacy of waste separation was recurrently exaggerated (mean=3.3), the significance of meat-eating (mean=2.9) or flying was continually understated. On the other hand, the broader PEB score was 2.59 out of 5, signaling respondents displayed environmentally significant behaviors 52% of the time (2.59/5).

Moreover, concerning pro-environmental actions, this paper confirmed and refined Kollmuss and Agyeman (2002) and Zsóka et al. (2013) arguments, conveying the expected disparity between pro-environmental values and actions. The disparity between the better-defined portion of participants choosing stronger beliefs on actions' usefulness and the less committed action engagement, exposed to view the widely reported value-action gap, validating H1a.

Secondly, the correlational asymmetries among different PEBs suggested noteworthy differences in the sizes of the value-action gaps of distinct behaviors, corroborating H1b. Gaps were most pronounced amongst recycling and car usage avoidance, as no significant correlations were found amid believed usefulness and action frequency. Accordingly, this paper suggests the incongruency among environmental consciousness of recycling and engagement, stemmed from an increasing embeddedness of the former in social practices. Additionally, and consistently with the well-accounted reluctance to adjust transportation habits (Whitmarsh et al., 2009, 2011), respondents did not act in accordance with one's noteworthy understanding of the environmental impacts of driving. Rather than trimming car habits, higher predispositions to adopt energy conservation actions or recycle were displayed. The least prominent disparities occurred among dietary-related behaviors. In fact, despite the common lack of awareness on the prospects of avoiding meat-intake, the cognition of this action efficacy was positively associated with its adoption. These results highlight the potential of education and informational approaches to prompt this particular behavior genre.

As expected, baseline regression analyses explained overall little variance levels. As even properly informed respondents appeared to not often behave in accordance with their beliefs, notably in the case of travel habits, this paper pointed to the assortment of factors synergistically influencing people's environmentally-supportive behavior, steering the second research question addressed.

As previously theorized, TCFM's aim was twofold. Beyond providing information and customized action-plans, the intervention intended to build capacities at the local levels. Participants could easily visualize their relative emissions and prioritize focus areas for impactful action. The concurrent intention was to provide a hotspot diagnosis from a policy standpoint. This dissertation stemmed from a concerted effort to identify the relative environmental impacts of different processes while enlarging understanding on the factors influencing behavioral choices. The former elements (e.g. inhibitors) are improbably uniformly spread over different consumption domains. Thus, such examination was conducted to clarify differences across the appraised segments of food, personal transportation, and household-energy consumption.

This paper set out by ascertaining to which degrees were the public properly equipped to embrace lower-carbon lifestyles. Despite significant higher appreciation on the relative impacts of food consumption, motivation, and ability to reduce emissions were most pronounced among home-related carbon-generating activities, partially authenticating H2a. Contrasting with the value-action gap, associations between knowledge and attitudes were evidenced. Higher literacy scores moved in tandem with more pro-environmental values.

Adjoining the former, by downscaling emissions to the personal level, an alternative consumption-sided approach to climate change was applied. Carbon footprint outcomes appeared to be in line with European averages. An average of 7.68 CO_2 tonnes per participant, resembled 2018 Eurostat footprint estimations of 7.0 tonnes per capita.

Secondly, by disaggregating people's environmental impacts into the considered consumption categories, this paper's findings supported the hypothesis that carbon repercussions are not spread uniformly over different segments (H2a). The end-point contribution analysis identified personal transportation and food consumption as the major CF drivers. These findings partially tally with those of Ivanova et al. (2016), while simultaneously refute those of other studies. Contradicting Tukker et al. (2010) or Matuštík and Kočí (2019) conclusions on energy contributions, this paper did not find the aforementioned to exert a significant impact on per capita CFs.

Contingent on these conclusions, empirical findings on the most critical consumption domains suggested CF size and composition to be interrelated with lower carbon literacy levels. Accordingly, results indicated higher proportions of mobility and food sourced-emissions to be associated with lower psychological and physical capacities (ability and motivation) to lessen ecological footprints. These findings partially corroborate the hypothesis in point (H2b). The latter is only refuted at the energy domain. This evidence highlighted the potential of targeted informational approaches as an avenue for steering action, and to be most salient amid consumption domains where respondents display lower baseline literacy levels, compounded by relatively higher emissions.

However, this dissertation does not predominantly (or uniquely) ascribed respondents' low carbon literacy levels as the roots of a generalized disengagement with lower-carbon patterns. Rather, in tune with sizeable literature (Lorenzoni et al., 2007; Whitmarsh, 2009b), the previous analysis suggested current provision schemes to be seldom conducive to pro-environmental practices. To contribute to the discussion on why high-magnitude carbon-savings remain widely unfulfilled, this paper elaborated on the perceived internal and external barriers to low-carbon lifestyles.

Although no significant associations were found among barriers perceived and CFs, this paper mapped out new findings. It remarked different constraints to oftentimes overlap, or conjointly operate, to escalate engagement curtailments. Particularly, perceived lack of supportive mobility infrastructures, coupled with convenience reasons, was associated with higher mobility footprints. Lastly, the most reported reasons for inaction included perceived lack of enabling infrastructures (58.1%), convenience constraints (48.4%), and lack of locally available information (44.1%).

Moreover, the common knowledge dearth set the scientific ground for this study's utmost purpose. With 75,3% agreeing to "I need more information to become more environmentally-friendly" and nearly half of the sample reporting "I find it difficult to apply information about reducing my CF to my daily life", this paper overriding aim relied on carbon literacy enhancement.

Addressing the research question regarding the intervention's outcomes, this dissertation advocates the efficacy of game-based sustainability programs, as the one here depicted, in carbon literacy enhancement. Participants reported significant literacy enlargements of 23% over the intervention course, and uttermost, doubled their motivation to act, confirming H3a.

Moreover, this paper argues, following this intervention, there was an increased motivation towards footprint mitigation, remarkably when individuals displayed higher carbon emissions' comprehension, as well as a higher psychological and physical ability to engage in sustainable consumption. These findings reinforce earlier research, indicating information provision alone, despite imperative, is insufficient to elicit personal engagement, as illustrated by a pre-intervention, weak correlation among literacy constructs (Whitmarsh et al., 2009). Such correlational improvement suggested better alignment among literacy constituents upon TCFM. Hence, this paper argues taking part in a gamified intervention might have fostered sustainability engagement: a precondition to spur meaningful action, as hereupon discussed.

Having settled on the TCFM effectiveness in carbon literacy enhancement, the research question remainder aimed to appraise the extent to which TCFM motivated behavioral change. Beyond empowering users to explore environmental impacts, the optional pledge section enabled analysis on TCFM efficacy at inducing environmental action-intention. As predicted in H3b, simply partaking in TCFM seemed to drive respondents to embrace a new ethos, with 92 out of 93 participants intending to implement at least some suggestions.

Differences among consumption areas, unveiled respondents were significantly most inclined to undertake household-related greener activities, like recycling or better energy and water management, as these often entail minor changes. Furthermore, when presented with a list of 15 alternative mitigation strategies, covering all sections, approximately ranked from highest to lowest impact in GHG mitigation, most professed intentions in terms of low-impact practices, as those often require little effort and sacrifice. These findings tally with those of Whitmarsh (2009b) and Boyes et al. (2009), underlining pro-environmental behavioral changes to hinge-on the lifestyle aspects affected and the perceived hassle level entailed. Accordingly, smaller sample proportions were prepared to reduce meat-consumption, take alternatives to flying, live car-free, or install/upgrade insulation.

The differential intention to adopt different pro-environmental behaviors was analogous to that reported for carbon literacy. Analysis indicated primarily respondents already displaying baseline promising evaluations on knowledge, ability, and motivation to mitigate emissions, were more disposed to embrace lower-carbon lifestyles. Ecologically aware and committed individuals may be the catalyst to a shift towards a low-carbon paradigm.

Lastly, the outcomes of the intervention were compared for different user-groups. Carbon literacy increases were most pronounced among the German group. Simultaneously, the Italian followed by the German sample were the sections most willing to change behaviors upon the intervention.

In summary, backing programs like TCFM appeared to have the potential to raise carbon literacy and spur intent-oriented climate change action. Answers to an open-ended question revealed TCFM as an "eye-opening" experience and disclosed increases in literacy to better align with fun and engaging interventions, ratifying H3c. Concurrently, the evidence-base generated contributes towards the background for policymaking and future research. In particular, extensive attentiveness should be devoted to dietary and mobility aspects, as beyond comprising lower literacy levels, these entailed more frequent barriers and substantially aggravated environmental impacts. Thus, apart from carbon education, urging knowledge and skills, the public would benefit from supportive measures. External interventions targeting time, convenience, and monetary cost reductions of greener alternatives are essential to induce lower-carbon lifestyles. Consistent with Zsóka et al. (2013), this paper argues environmental consciousness, action, and education to be interrelated. Empowering and engaging informational approaches, supported by governance structures and policy adjustments, might pave the way to a low-carbon era.

5 Conclusions

This section presents an overview of the primary research conclusions. Additionally, implications for practitioners and policymakers are discussed, limitations identified, and future research suggestions are provided.

5.1 General Conclusions

Experts and policymakers increasingly alert for the urgent need to induce societal engagement in climate change mitigation. Recent research indicated households' unsustainable consumption as directly or indirectly accountable for GHG emissions' growth. Additionally, studies on emissions' drivers, postulated technological solutions alone as insufficient to transit towards low-carbon societies, emphasizing households' vital role in rallying for this cause.

This thesis' overreaching theme aimed at appraising the extent to which a gamification-based system can increase awareness and influence the meanings and cognizance that are prone to govern people's carbon-producing practices. The present work adds several contributions to this discussion.

Firstly, refining on prior literature, results showed people's misconceptions regarding the environmental effects of their actions prevailed. In particular, the limited reported awareness on the efficacy of meat-reduced diets, or the lack of acquaintance with CF conceptualizations, vindicated the aforementioned. One may simultaneously argue the common lack of knowledge and inaptitude to link lifestyle choices to emissions, partially gives rise to limited behavioral responses to climate change. Hence, baseline measurements revealed few people regularly engaged in actions beyond recycling or private energy conservation. These results go along with previous findings (Whitmarsh et al., 2009), highlighting the pressing needs for informational approaches aimed at bridging the knowledge gap signaled. The present work suggests gamified educational pedagogies as potential approaches to start addressing the former quandary.

Following the carbon literacy definition theorized in the literature review, this paper has shown all three dimensions (knowledge, ability, and motivation) to report significant increases upon TCFM participation. As previously postulated, participants increased, over the program course, literacy levels on average by 23%.

Although this initiative laid upon providing a conjecture for carbon literacy enhancement, our findings suggested the sole completion of the tool also raised the potential for changing attitudes, paving the way for comprehensive behavior transitions. Ergo, this paper also contributes to the recent body of literature claiming the potential of voluntary consumer-oriented programs to shift behaviors and reduce CFs up to 20% (Jones & Kammen, 2011).

In fact, results upon program partaking unveiled behavioral responses to climate change, but only up to certain extents. Responses were most commonly in terms of deeds calling for little effort or sacrifice. Consistent with Druckman and Jackson (2009), domestic energy conservation measures were recurrently mentioned as practices one was to change. On the other hand, aligned with broad evidence (Lorenzoni et al., 2007; Whitmarsh, 2009a), the opposite was rather verifiable for harder-to-change behaviors. Despite eminent awareness on the efficacy of car usage or flying reduction, pledges to undertake changes among those domains were relatively scarce.

The disparity among environmental awareness and pro-environmental actions set the scientific background for a farther contribution. This paper disclosed sundry evidence on the value-action gap. However, it also advocated that information provision alone, and motivation to act are paramount but likely insufficient to induce behavior changes, as knowledge prospects are generally hindered if the environment lacks basic affordances.

This thesis argued behaviors are entrenched within social contexts. Ingrained economic, structural, and contextual barriers pose further challenges, worsening the cognitive dissonance here discussed. For instance, the little uptake of alternatives to drive or fly summons the demand for more supportive provision systems. Hence, to spur meaningful action, this paper leveraged the urgency to address structural constraints at the individual level, and properly equip the public to engage in voluntary environmentalism.

Consequently, this thesis' additional contribution embodies a heads-on setting. Framed-up for primary data collection, it pertains to fetch policymakers and other stakeholders on the infrastructural shifts needed to empower lower-carbon lifestyles.

To conclude, this study legitimizes high-magnitude carbon emissions to be locked-in at the household level, and the potentiality of gamified interventions to unlock substantial reductions. This dissertation adds to the growing literature body by introducing the feasibility of an embryonic empirical mechanism. The former yields the means to empower individuals on the most effective pathways to CF reduction, while mediating an identification analysis of the hotspots requiring structural changes.

5.2 Implications for Practitioners

This dissertation contributes with a handful of insights for the design of interventions aimed at carbon literacy enhancement and pro-environmental behavior stimulation.

TCFM emerged as a suitable approach to raise carbon literacy and, subsequently, incite behavioral change. Given the prevailing misconceptions on behaviors' environmental impacts, this paper suggests consumption-based accounting models, if carefully engendered, as promising tools to realize community engagement and sustainable consumption enthusiasm. Findings suggested that while engendering this sort of interventions, practitioners need to take human informational needs into consideration. These approaches must be tailored to one's situated context, values, and beliefs, providing personal emissions assessments and actionable mitigation pathways.

Results confirmed and refined the key role of a careful consideration throughout the system design and its content settlement, as elsewhere argued (West et al., 2016). Empirical results revealed users' active uptake of new knowledge at each system interplay, thereby suggesting the formerly detailed methodology as an instrument to guide the development of gamification-based systems.

Findings showed gamification as a compelling strategy to ease learning and proficiency in complex matters. Appraisals on TCFM, blended in with literature on instructional design and climate change education, authenticated several elements in literacy enhancement, while occasioning environments for behavioral changes. Apart from the provision of meaningful feedback, informational approaches must simultaneously imply some freedom degree, while remaining intuitive. Accordingly, this paper suggests tools should be designed to empower individuals in exploring the environmental impacts of specific choices. In particular, the pledge function here postulated, by presenting an assorted list of options and respective impacts, allowed users to select and customize the most suitable course of action to reduce CFs, thereby resonating to people's values, worldviews, and specific circumstances.

Another important element to induce knowledge building in interventions alike embodies the power of positive social pressure. TCFM enabled participants to explore one's footprint but also those of others and European averages. Therefore, in designing interventions creating a sense of competition and citizenship, through opportunities for social comparison, emerges as a key element to shift mindsets and eventually behaviors.

The overall consideration of these and other previously exploited implications might step-up the provisioning process of information, countering the public's tendency to understate one's impact, as elsewhere reported (Whitmarsh et al. 2009).

To sum up, following the recommendations presented in the literature section and by meticulously leveraging game affordances, one may argue the utmost contribution of this dissertation to be the archetype devised and its procedure. Offering actionable feedback, encouraging informed efforts, inciting peer-pressure, and allowing for emissions' benchmarking, TCFM contributes to enhancing CF governance by virtue of greater individual participation.

5.3 Implications for Policymakers

This dissertation unveiled large carbon emissions reductions may be shortly enacted through voluntary behavior change. Therefore, backing programs like TCFM bear the potential to usher in awareness and public engagement in action. In fact, The European Environment Agency (2013) has already accredited the potential of interventions of this sort in climate change mitigation.

However, findings also indicated information provision schemes are oftentimes embedded by structural and cultural contexts, constraining households' dynamics, decisions, and systemic transitions to low-consumption paradigms. Accordingly, the goal of this tool was to advocate greater engagement among consumers and society, to co-create a lower-carbon tomorrow. Thus, in tandem with information dissemination, this system collected actors' data to expose policy specificities that could facilitate and motivate communities' incremental changes.

As repeatedly noted in previous studies, policymakers, practitioners, and academics appear to be undergoing an increasing appeal towards the role communities can play in the transformational decarbonization conveyed by the 2°C climate target (West et al., 2016). Consequently, inferences drawn stressed climate policy responses would benefit from thorough assessments on pro-environmental behavioral barriers. To determine the actual feasibility of civic engagement with sustainable consumption, the extra contribution of this study relied on the identification of the hotspots calling for structural adjustments.

Results suggested notable links among motivation and the accessibility and appeal of lower-carbon options. Meaning, information, and users' power over lifestyle choices, are insufficient to encourage adoption and endorsement of less favorable behaviors, as those entailing higher monetary, time, or behavioral costs.

For instance, this study found personal transportation as the segment contributing the most towards material footprints. In addition, a thorough appraisal revealed a lack of enabling and equitable mechanisms. As indicated in the discussion, the little adoption of sustainable mobility alternatives calls for institutions and infrastructures guiding behaviors to be altered. Potential avenues include supportive interventions to bring habitual behaviors to a halt while turning greener alternatives equally or more appealing.

Lastly, consumer-empowerment policy is mainly focused on reducing constraints on individuals' actions. However, different barriers call for dissimilar strategies. Thus, this thesis stresses the need for a plurality of approaches to reduce CFs per capita. The insights gathered on barriers may provide some guidance to tailor strategies.

To conclude, this thesis exhibits people's environmental understandings and motivations would benefit from the combination of carbon literacy information, endorsing know-how and skills, proliferated within an empowering provision framework, advocating options for low-carbon lifestyles.

5.4 Limitations and Future Research

A retrospective outlook on the presented study evidenced that, while advancing primordial contributions to the field, it faced inevitable limitations.

Firstly, the intervention was arranged amid April 2020. This period might have been non-optimal as it comprised unprecedented times due to the novel coronavirus. Therefore, the experience was more predisposed to extraordinary variances.

Secondly, results were obtained using a convenience sample. The limited respondents' amount and diversity restrained this study's general applicability. In particular, results concerning the differences among nationalities cannot be generalized. Future research should prospect on how to extend this study to a more representative sample.

Thirdly, consistent with previous literature concerns, social desirability, and other response bias likely exerted influence on self-reported measures (Thøgersen and Ölander, 2006). To help tackling accuracy discrepancies, changes over time, rather than absolute scores, were applied when possible. Additionally, following Milfont (2009) reasoning, to hedge against social desirability username selection was encouraged, safeguarding one's anonymity. Lastly, self-reported data quality might have also been hindered by respondents' unintentional misconceptions of consumption (e.g. km traveled, kWh used, euros spent). The latter was coupled with another caveat: CF calculation methodology.

TCFM laid out a bottom-up consumption-based footprint calculation. Given the variety of available approaches to analyze CFs, the methodology entailed was selected in the interest of usability and customization. Moreover, for simplicity purposes and to assure the intervention was not intrusive or time-consuming, only general, and modest data was queried. This brought a handful of shortcomings, namely lack of detail and precision, and only fairly comparable results with those of similar tools. Hence, it is crucial to emphasize uncertainty concerning the data retrieved.

Therefore, CF calculations' standardization is needed, as this field is far from consolidated. The scientific quality of tools alike would benefit from data and scope consistency. Secondly, whereas improvements in the technical details, namely data quality, assumptions, and methodology, are in great demand, the fundamental virtue of these interventions lays upon its ability to reach users, raise awareness, and ultimately change behaviors. Too much information hinders the main message delivery, whereas too little may restrict figures' meaningfulness and tailored content. Future research should pursue the debate among accuracy versus consistency and render novel insights on the optimal circumstantial approach.

Suggestions to improve the tool requiring no additional resources are listed hereupon. A group feature, creating online communities via social media (e.g. WhatsApp, Facebook groups), could prompt social connections and interactions with like-minded individuals. To capture an international audience, TCFM relied on many generalizations. Integration of alternative consumption choices (e.g. public transportation usage) and inclusion of country-specific emission factors would improve user experience, especially among those critical-reflexive participants. Additionally, a more detailed and nuanced discussion on the ongoing engagement challenge stands in need. Therefore, as baseline CFs were already provided, suggestions include goal-setting and CF progress monitoring features. Bi-monthly challenges could be engendered, measuring post-challenge CFs, and rewarding reductions. Lastly, unification of TCFM under one only platform is fundamental.

The latter recalls gamification is often resource-consuming. TCFM failed to include paramount features, given monetary and time constraints. Unconstrained endeavors could consider a mobile application format, allowing users to constantly track footprints, while avoiding manual time-consuming data inputs. Direct feedback is absent, in the sense these tools imply separate applications disconnected from the practices aimed at change. Hence, this thesis suggests future research should be allocated on mechanisms to embed technical solutions alike into people's everyday practices, materializing emissions, while raising environmental cues for sustainability (e.g. automated data collection and green notification-reminders).

Finally, one must also note, this research lacked comparable data to examine literacy contrasts among participants and non-participants for the same period. However, one may argue it is highly farfetched literacy increases recorded to be a general phenomenon, rather than this intervention's outcome. Building upon the findings, future research could adopt a comparative analysis configuration with a control group.

Lastly, this work opens the door for in-depth research on how to formulate gamified interventions to motivate carbon literacy. More research is needed to devise measures that better operationalize carbon literacy, carbon footprint and barriers to pro-environmental behavior. Further work could build upon this thesis and exploit linkages with state-of-the-art taxonomies, namely carbon capability.

References

Abrahamse, W., Steg, L., Vlek, C., & Rothengatter, T. (2005). A review of intervention studies aimed at household energy conservation. *Journal of Environmental Psychology*, *25*(3), 273–291. https://doi.org/10.1016/j.jenvp.2005.08.002

Aichholzer, G., Allhutter, D., & Strauß, S. (2012). Using online carbon calculators for participation in local climate initiatives. *Lecture Notes in Computer Science (Including Subseries Lecture Notes in Artificial Intelligence and Lecture Notes in Bioinformatics)*, *7444 LNCS*, 85–96. https://doi.org/10.1007/978-3-642-33250-0_8

Attari, S. Z., DeKay, M. L., Davidson, C. I., & de Bruin, W. B. (2010). Public perceptions of energy consumption and savings. *Proceedings of the National Academy of Sciences of the United States of America*, *107*(37), 16054–16059. https://doi.org/10.1073/pnas.1001509107

Bottrill, C. (2007). Internet-based tools for behaviour change. *Defense*, 1917–1929. http://www.eci.ox.ac.uk/research/energy/downloads/eceee07/bottrill.pdf

Boyes, E., Skamp, K., & Stanisstreet, M. (2009). Australian secondary students' views about global warming: Beliefs about actions, and willingness to act. *Research in Science Education*, *39*(5), 661–680. https://doi.org/10.1007/s11165-008-9098-5

Boyes, E., & Stanisstreet, M. (2012). Environmental Education for Behaviour Change: Which actions should be targeted? *International Journal of Science Education*, *34*(10), 1591–1614. https://doi.org/10.1080/09500693.2011.584079

Cheremisinoff, N. P. (2011). Pollution Management and Responsible Care. In *Waste* (pp. 487–502). Elsevier Inc. https://doi.org/10.1016/B978-0-12-381475-3.10031-2

DEFRA. (2008). *A framework for pro-environmental behaviours. London: DEFRA*. www.defra.gov.uktel:02072386000Website:www.defra.gov.ukhttp://www.opsi.gov.uk/click-use/value-added-licence-information/index.htm

Defra. (2010). *Public Attitudes and Behaviours towards the Environment - Lifestyle Omnibus Survey*. www.defra.gov.uk

Department for Business Energy and Industrial Strategy. (2019). *2019 Government Greenhouse Gas Conversion Factors for Company Reporting. Methodologhy Paper for Emission Factors.* www.nationalarchives.gov.uk/doc/open-government-licence/

Deterding, S., Dixon, D., Khaled, R., & Nacke, L. (2011). From game design elements to gamefulness: Defining "gamification." *Proceedings of the 15th International Academic MindTrek Conference: Envisioning Future Media Environments, MindTrek 2011*, 9–15. https://doi.org/10.1145/2181037.2181040

Dietz, T., Gardner, G. T., Gilligan, J., Stern, P. C., & Vandenbergh, M. P. (2009). Household actions can provide a behavioral wedge to rapidly reduce US carbon emissions. *Proceedings of the National Academy of Sciences of the United States of America*, *106*(44), 18452–18456. https://doi.org/10.1073/pnas.0908738106

Druckman, A., & Jackson, T. (2009). The carbon footprint of UK households 1990-2004: A socio-economically disaggregated, quasi-multi-regional input-output model. *Ecological Economics*, *68*(7), 2066–2077. https://doi.org/10.1016/j.ecolecon.2009.01.013

Druckman, A., & Jackson, T. (2015). Understanding households as drivers of carbon emissions. In *Taking Stock of Industrial Ecology* (pp. 181–203). Springer International Publishing. https://doi.org/10.1007/978-3-319-20571-7_9

Dunlap, R. (2008). The new environmental paradigm scale: From marginality to worldwide use. In *Journal of Environmental Education* (Vol. 40, Issue 1, pp. 3–18). Heldref. https://doi.org/10.3200/JOEE.40.1.3-18

Dunlap, R. E., van Liere, K. D., Mertig, A. G., & Jones, R. E. (2000). New Trends in Measuring Environmental Attitudes: Measuring Endorsement of the New Ecological Paradigm: A Revised NEP Scale. *Journal of Social Issues*, *56*(3), 425–442. https://doi.org/10.1111/0022-4537.00176

European Commission. (2019). *Special Eurobarometer 490 Summary Climate Change Survey requested by the European Commission* (Issue April 2019). https://doi.org/10.2834/00469

Eurostat. (2018). Household consumption by purpose- Statistics Explained. In *Eurostat* (Issue November). https://ec.europa.eu/eurostat/statistics-explained/index.php?title=Household_consumption_by_purpose

Field, A. (2015). Discovering Statstics using SPSS. In *Bangladesh Journal of Plant Taxonomy* (Vol. 22, Issue 2).

Gardner, G. T., & Stern, P. C. (2008). The Short List: The Most Effective Actions U.S. Households Can Take to Curb Climate Change. *Environment*, *50*(5), 12–25. https://doi.org/10.3200/ENVT.50.5.12-25

Gifford, R., Kormos, C., & McIntyre, A. (2011). Behavioral dimensions of climate change: Drivers, responses, barriers, and interventions. *Wiley Interdisciplinary Reviews: Climate Change*, *2*(6), 801–827. https://doi.org/10.1002/wcc.143

Girod, B., van Vuuren, D. P., & Deetman, S. (2012). Global travel within the 2°C climate target. *Energy Policy*, *45*, 152–166. https://doi.org/10.1016/j.enpol.2012.02.008

Hamari, J., Koivisto, J., & Sarsa, H. (2014). Does gamification work? - A literature review of empirical studies on gamification. *Proceedings of the Annual Hawaii International Conference on System Sciences*, 3025–3034. https://doi.org/10.1109/HICSS.2014.377

Hawcroft, L. J., & Milfont, T. L. (2010). The use (and abuse) of the new environmental paradigm scale over the last 30 years: A meta-analysis. *Journal of Environmental Psychology*, *30*(2), 143–158. https://doi.org/10.1016/j.jenvp.2009.10.003

Hertwich, E. G., & Peters, G. P. (2009). Carbon footprint of nations: A global, trade-linked analysis. *Environmental Science and Technology*, *43*(16), 6414–6420. https://doi.org/10.1021/es803496a

Howell, R. A. (2018). Carbon management at the household level: a definition of carbon literacy and three mechanisms that increase it. *Carbon Management*, *9*(1), 25–35. https://doi.org/10.1080/17583004.2017.1409045

IPCC, I. G. P. for C. C. (2007). *Climate Change 2007 Synthesis Report* (Vol. 104).

IPCC, I. G. P. for C. C. (2016). *Summary for Policymakers — Global Warming of 1.5 °C*. https://www.ipcc.ch/sr15/chapter/spm/

Ivanova, D., Stadler, K., Steen-Olsen, K., Wood, R., Vita, G., Tukker, A., & Hertwich, E. G. (2016). Environmental Impact Assessment of Household Consumption. *Journal of Industrial Ecology*, *20*(3), 526–536. https://doi.org/10.1111/jiec.12371

Jackson, T. (2005). Motivating Sustainable Consumption: A Review of Evidence on Consumer Behaviour and Behavioural Change. A Report to the Sustainable Development Research Network. In ... (Issue January). www.surrey.ac.uk/CES

Jones, C. M., & Kammen, D. M. (2011). Quantifying carbon footprint reduction opportunities for U.S. households and communities. *Environmental Science and Technology*, *45*(9), 4088–4095. https://doi.org/10.1021/es102221h

Kim, B., & Neff, R. (2009). Measurement and communication of greenhouse gas emissions from U.S. food consumption via carbon calculators. *Ecological Economics*, *69*(1), 186–196. https://doi.org/10.1016/j.ecolecon.2009.08.017

Kollmuss, A., & Agyeman, J. (2002). Mind the Gap: Why do people act environmentally and what are the barriers to pro-environmental behavior? *Environmental Education Research*, *8*(3), 239–260. https://doi.org/10.1080/13504620220145401

Laakso, S., & Lettenmeier, M. (2016). Household-level transition methodology towards sustainable material footprints. *Journal of Cleaner Production*, *132*, 184–191. https://doi.org/10.1016/j.jclepro.2015.03.009

Lorenzoni, I., Nicholson-Cole, S., & Whitmarsh, L. (2007). Barriers perceived to engaging with climate change among the UK public and their policy implications. *Global Environmental Change*, *17*(3–4), 445–459. https://doi.org/10.1016/j.gloenvcha.2007.01.004

Matuštík, J., & Kočí, V. (2019). Environmental impact of personal consumption from life cycle perspective – A Czech Republic case study. *Science of the Total Environment*, *646*, 177–186. https://doi.org/10.1016/j.scitotenv.2018.07.233

Milfont, T. L. (2009). The effects of social desirability on self-reported environmental attitudes and ecological behaviour. *Environmentalist*, *29*(3), 263–269. https://doi.org/10.1007/s10669-008-9192-2

Pandey, D., Agrawal, M., & Pandey, J. S. (2011). Carbon footprint: Current methods of estimation. *Environmental Monitoring and Assessment*, *178*(1–4), 135–160. https://doi.org/10.1007/s10661-010-1678-y

Robson, K., Plangger, K., Kietzmann, J. H., McCarthy, I., & Pitt, L. (2015). Is it all a game? Understanding the principles of gamification. *Business Horizons*, *58*(4), 411–420. https://doi.org/10.1016/j.bushor.2015.03.006

Scarborough, P., Appleby, P. N., Mizdrak, A., Briggs, A. D. M., Travis, R. C., Bradbury, K. E., & Key, T. J. (2014). Dietary greenhouse gas emissions of meat-eaters, fish-eaters, vegetarians and vegans in the UK. Climatic Change, 125(2), 179–192. https://doi.org/10.1007/s10584-014-1169-1

Seaborn, K., & Fels, D. I. (2015). Gamification in theory and action: A survey. *International Journal of Human Computer Studies*, *74*, 14–31. https://doi.org/10.1016/j.ijhcs.2014.09.006

Springmann, M., Clark, M., Mason-D'Croz, D., Wiebe, K., Bodirsky, B. L., Lassaletta, L., de Vries, W., Vermeulen, S. J., Herrero, M., Carlson, K. M., Jonell, M., Troell, M., DeClerck, F., Gordon, L. J., Zurayk, R., Scarborough, P., Rayner, M., Loken, B., Fanzo, J., … Willett, W. (2018). Options for keeping the food system within environmental limits. *Nature*, *562*(7728), 519–525. https://doi.org/10.1038/s41586-018-0594-0

Steg, L., & Vlek, C. (2009). Encouraging pro-environmental behaviour: An integrative review and research agenda. *Journal of Environmental Psychology*, *29*(3), 309–317. https://doi.org/10.1016/j.jenvp.2008.10.004

Stern, P. C. (2000). New Environmental Theories: Toward a Coherent Theory of Environmentally Significant Behavior. *Journal of Social Issues*, *56*(3), 407–424. https://doi.org/10.1111/0022-4537.00175

Thøgersen, J. (2005). How may consumer policy empower consumers for sustainable lifestyles? In *Journal of Consumer Policy* (Vol. 28, Issue 2, pp. 143–177). Springer. https://doi.org/10.1007/s10603-005-2982-8

Thøgersen, J., & Ölander, F. (2006). To what degree are environmentally beneficial choices reflective of a general conservation stance? *Environment and Behavior*, *38*(4), 550–569. https://doi.org/10.1177/0013916505283832

Thornton, A. (2009). Public attitudes and behaviours towards the environment - tracker survey: A report to the Department for Environment, Food and Rural Affairs. TNS. Defra, London. *TNS Defra London*, *September*, 1–91. www.defra.gov.uk

Truelove, H. B., & Parks, C. (2012). Perceptions of behaviors that cause and mitigate global warming and intentions to perform these behaviors. *Journal of Environmental Psychology*, *32*(3), 246–259. https://doi.org/10.1016/j.jenvp.2012.04.002

Tukker, A., Cohen, M. J., Hubacek, K., & Mont, O. (2010). The Impacts of household consumption and options for change. *Journal of Industrial Ecology*, *14*(1), 13–30. https://doi.org/10.1111/j.1530-9290.2009.00208.x

UNFCCC. (2015). Adoption of the Paris Agreement. In *Conference of the Parties on its twenty-first session* (Issue December). https://doi.org/FCCC/CP/2015/L.9

Werbach, K., & Hunter, D. (2015). *The Gamification Toolkit: Dynamics, Mechanics, and Components for the Win*.

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. *Journal of Industrial Ecology*, *20*(3), 396–409. https://doi.org/10.1111/jiec.12372

Whitmarsh, L. (2009a). What’s in a name? Commonalities and differences in public understanding of climate change and global warming. *Public Understanding of Science*, *18*(4), 401–420. https://doi.org/10.1177/0963662506073088

Whitmarsh, L. (2009b). Behavioural responses to climate change: Asymmetry of intentions and impacts. *Journal of Environmental Psychology*, *29*(1), 13–23. https://doi.org/10.1016/j.jenvp.2008.05.003

Whitmarsh, L. (2011). Scepticism and uncertainty about climate change: Dimensions, determinants and change over time. *Global Environmental Change*, *21*(2), 690–700. https://doi.org/10.1016/j.gloenvcha.2011.01.016

Whitmarsh, L., Neill, S. J. O., Seyfang, G., & Lorenzoni, I. (2009). Carbon Capability: what does it mean , how prevalent is it , and how can we promote it ? *Tyndall Centre for Climate Change Research: Technical Report 132*, *April*.

Whitmarsh, L., Seyfang, G., & O'Neill, S. (2011a). Public engagement with carbon and climate change: To what extent is the public "carbon capable"? *Global Environmental Change*, *21*(1), 56–65. https://doi.org/10.1016/j.gloenvcha.2010.07.011

Wiedmann, T., & Minx, J. (2007). *A Definition of "Carbon Footprint."* www.censa.org.uk

Wright, L. A., Kemp, S., & Williams, I. (2011). "Carbon footprinting": Towards a universally accepted definition. In *Carbon Management* (Vol. 2, Issue 1, pp. 61–72). https://doi.org/10.4155/cmt.10.39

Wynes, S., & Nicholas, K. A. (2017). The climate mitigation gap: Education and government recommendations miss the most effective individual actions. *Environmental Research Letters*, *12*(7), 74024. https://doi.org/10.1088/1748-9326/aa7541

Xu, Y. (2011). Literature Review on Web Application Gamification and Analytics. *Honolulu, HI*, *August*, 11--05. http://csdl.ics.hawaii.edu/techreports/11-05/11-05.pdf

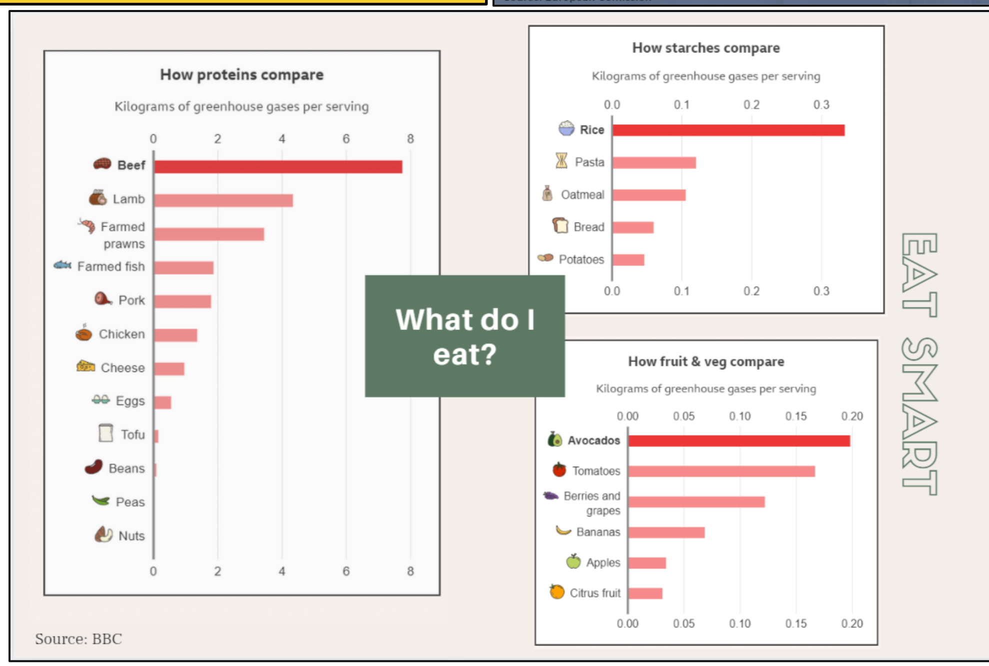
Zsóka, Á., Szerényi, Z. M., Széchy, A., & Kocsis, T. (2013). Greening due to environmental education? Environmental knowledge, attitudes, consumer behavior and everyday pro-environmental activities of Hungarian high school and university students. *Journal of Cleaner Production*, *48*, 126–138. https://doi.org/10.1016/j.jclepro.2012.11.030

Appendices

Appendix 1 Affordance Types and Corresponding Motivational Sources and Design Principles (Xu et al., 2016)

Motivational Affordances	**Motivational Sources**	**Design Principles**
Points, Badges, Levels, Clear goals, Feedback, Progress, Challenge, Reward	Cognitive: Competence and achievement	Systems provide various challenge levels or immediate performance feedback
Leaderboard	Social & Psychological: Leadership and followership	Systems facilitate one's desire to influence others, or influenced by others
Story/Theme	Emotional: Affect and emotion; Psychological: Autonomy and the Self	Systems induce intended emotions via interaction with the system or promote creation and representation of self-identity.
Rewards	Extrinsic motivators	Systems provide incentives for certain actions.

Appendix 2 Example of Tips, Tricks, and Incentives for Environmentally Friendly Behavior



Appendix 3 The Carbon Footprint Movement: Surveys, Infographic and User-Journey

The Carbon Footprint Movement: Gamified surveys' links

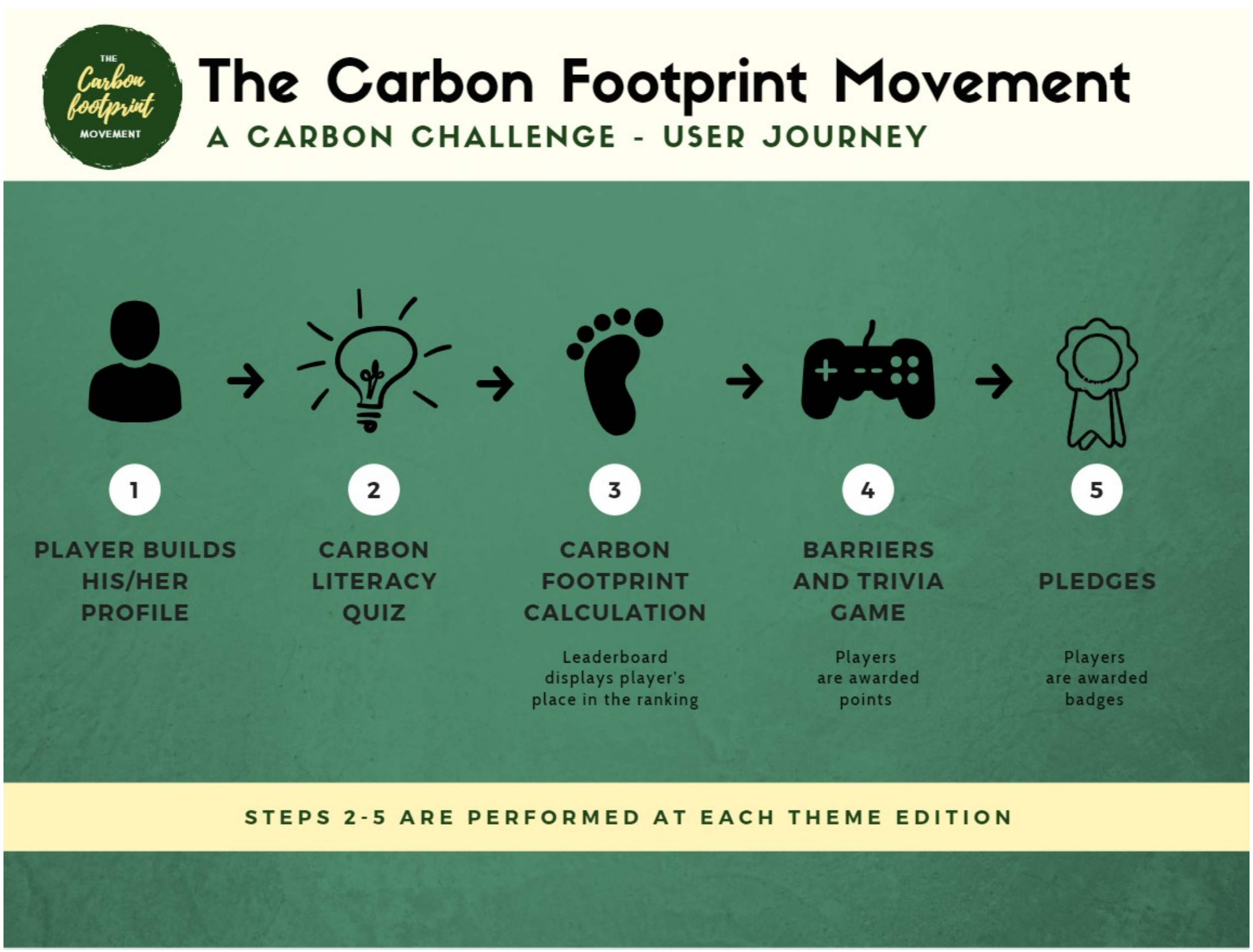
Baseline Survey: https://landbot.io/u/H-428211-09LHNOT7WT9EP0HC/index.html

Food Edition: https://landbot.io/u/H-436140-ZSW4OEXMLQCT6JS2/index.html

Mobility Edition: https://landbot.io/u/H-445783-LNQC7SCBP5MQX32I/index.html

Household Edition: https://landbot.io/u/H-457046-SKULNECPGTJG2807/index.html

The Carbon Footprint Movement: User-journey



The Carbon Footprint Movement: Infographic

Appendix 4 Methodology of Carbon Footprint Calculation

The methodology adopted for developing the carbon footprint calculator followed a simplified version of the procedures publicly defined by the UK Government (Department for Business Energy and Industrial Strategy, 2019).The Carbon Footprint Movement collects participants' bottom-up data and calculates one's carbon footprint per year, using "Greenhouse gas reporting: conversion factors 2019".

> "An emission factor is a representative value that attempts to relate the quantity of a pollutant released to the atmosphere with an activity associated with the release of that pollutant." (Cheremisinoff, 2011)

To calculate the combined environmental impacts, emissions factors were leveraged, which account for all GHG (e.g. CO_2, N_2O, methane etc.) released by the dissimilar activities reckoned. Therefore, the former were subsequently converted into the CO2 equivalent emissions and results presented in metric tonnes units. The carbon equivalent emission factors were then used to find the carbon footprint contribution from each source, on an annual basis. The corresponding factors were multiplied by participants reported spends to calculate per capita carbon footprints due to each source (see tables below). The calculations performed were sourced from DECC (Department of Energy and Climate Change) assessed methodology of an open-source carbon calculator. Assumptions and procedures are highlighted per consumption domain as follows.

Food: Participants were inquired about their dietary choices: High Meat Eater (> 100g of meat per day); Medium Meat Eater (=50 to 100g of meat per day); Low Meat Eater (< 50g of meat per day), Pescatarian (eats fish), Vegetarian or Vegan, and respective money amount (in €) spent on food and drinks on a weekly basis. Emissions calculations used corrections to the factors, provided by Scarborough et al. (2014). Table 4.1 displays the emission factors for different diet types, per weekly Euros spent on food and drinks.

Table 4.1 Emissions from food-related use.

Diet type	yearly tonnes of CO2 per weekly € spent on food & drinks
Heavy meat eater	0.0595
Medium meat eater	0.0470
Low meat eater	0.0385
Pescatarian	0.0323
Vegetarian	0.0315
Vegan	0.0240

Mobility: The mobility carbon footprint was further subdivided into air and road travel. Participants were instructed to not include business purposes traveling (air or road). Meaning, only personal trips were accounted for (occupational, educational, leisure).

Air Travel: Participants were asked about the number of flights taken over the past 12 months per flight type: short-haul (<3hours), medium-haul (3-6 hours) and long-haul (>6 hours). Table 4.2 displays the emission factors for different flight types, per yearly flights taken.

Road Travel: Footprint calculation was only available for car transportation modes (further research should include major public transportation modes as well). Car usage footprint was gauged from a combination of inquiries, namely, type of car (Sports car or large SUV: 7L/100Km; Small or medium SUV, or MPV: 5L/100km; City, small, medium car: 4.5L/100km; Electric car), type of fuel (Petrol, Diesel, LPG, CNG), and annual km driven.

Table 4.3 displays the emission factors for different car and fuel types per yearly km driven (as a driver or passenger).

Table 4.2 Emissions from personal transport (air travel)

Flight Type	tonnes Co2 per flight travelled (roundtrip)
Short haul flights	0.30
Medium Haul flights	0.45
Long haul flight	1.62

Table 4.3 Emissions from personal transport (four-wheelers).

Car Type/Size	Car Fuel	tonnes Co2 per km travelled
Sports car or large SUV (7l/100)	Petrol	0.000155
	Diesel	0.000182
	LPG	0.000107
	CNG	0.000031
Small or medium SUV, or MPV (5l/100)	Petrol	0.000111
	Diesel	0.000130
	LPG	0.000076
	CNG	0.000023
City, small, medium, large or estate car (4,5L/100)	Petrol	0.000099
	Diesel	0.000117
	LPG	0.000068
	CNG	0.000020
Electric	Electric	0.000060

House: There are several domestic emissions sources, namely cooking energy, electricity consumption, and private water supply. For brevity purposes, this paper household-related emissions' estimations were limited to electricity and natural gas consumption.

Electricity: Participants were asked about amounts used in kWh of electricity in the past 12 months.

Natural Gas: Participants were asked about amounts used in kWh of natural gas in the past 12 months

Lastly, individuals are asked to debrief the number of people in their households to calculate one's personal portion of the total household footprint. Individuals footprint were then estimated by dividing total energy amounts by number of people in one's household.

Table 4.3 displays the emission factors for each type of energy per yearly kWh spent. The former was gauged at the household level. Thus, to disaggregate it to the individual level further calculations should divide it by number of people at one's household.

Table 4.4 Sources of emissions in households

Energy Type	tonnes of CO2 per kWh of energy spent per annum
Natural Gas (kWh)	0.000180
Electricity (kWh)	0.000469

Appendix 5 Measures included in each Questionnaire

Pre & Post Series Intruments			
Constructs	**Measures**	**Items**	**Available responses**
Carbon Literacy		How much, if anything, would you say you know about the following terms?	A lot A fair amount Just a little Nothing (I only heard the name) Nothing (I never heard of it)
	Basic Knowledge & Understanding	Carbon Footprint	
	Understanding the sources & impact of carbon emissions as these relate to everyday activities	Carbon emissions of my personal actions and lifestyles choices Causes and consequences of carbon emissions on the climate	
	Relative impacts of different activities	The most effective actions to reduce my carbon emissions	
	Ability	I am able to obtain and understand information regarding my carbon footprint	Definitely yes Probably yes Might or might not Probably not Definitely not
	Motivation	Which of these best describes how you feel about your current lifestyle and the environment?	I'd like to do a lot more to help the environment I'd like to do a bit more to help the environment I don't know I'm ok with what I do at the moment I'm happy with what I do at the moment

Pre Series Intruments			
Constructs	**Measures**	**Items**	**Available responses**
Behaviors	Frequency of pro-environmental behaviour	How often do you engage in the following? Recycle Save water at home Save energy at home (e.g. use less heating, using saving bulbs) Use car less (Use public transport, walk or cycle instead) Take less leisure flights Avoid eating meat Buy local, seasonal, unprocessed foods	Always Often Sometimes Never
Behaviors	Perceived impact	Rate the impact of each above mentioned action in mitigating carbon emissions	A major impact A medium impact A small impact Would make no difference

During-Series Intruments			
Constructs	**Measures**	**Items**	**Available responses**
Carbon Literacy	Knowledge	How much would you say you know about the carbon emissions of your: *Food*: Diet *Mobility*: Transportation and travel behaviors *Household*: In-home behaviors	A lot A fair amount Just a little Nothing (I only heard the name) Nothing (I never heard of it)
	Ability	Are you able to reduce your _ carbon emissions? *Food*: Diet *Mobility*: transportation and travel lifestyle *Household*: in-home lifestyle	Definitely yes Probably yes Maybe Probably not Definitely not
	Motivation	How willing would you be to change your __ to make it more low-impact *Food*:Diet *Mobility*: Transportation and travel lifestyle *Household*: In-home behaviors	Very willing Fairly willing I don't know Not very willing Not willing at all
Barriers	Barriers	How if anything stops you from making more environmentally friendly choices in your: *Food*: Food Choices *Mobility*: Transportation & travel choices *Household*: Home	I don't know enough about these issues Lack of information Convenience reasons Financial reasons Infrastructural reasons Scepticism around climate change Habitual behavior Other issues are of greater importance
Behaviors	Action intent	Over the following year I pledge to: *Food:* Adopt a plant based diet Reduce my meat consumption Throw away less food Reduce my dairy consumption (milk, yogurts, eggs...) Eat more food that is locally in season *Mobility:* Taking fewer flights (excluding business purposes) Live car-free (as a driver & passenger) Buy/use more energy efficient (low carbon) vehicles Use Car Less (as a driver or passenger) Drive more economically *Household:* Install/Improve insulation producs Increase recycling Better energy management & usage Buy energy efficient products More responsible water usage	Definitely yes Probably yes Probably not Definitely not I already do this
Survey Perceptions	Perception	Please tell in a few words what did you think of this survey?	Open-ended question

Appendix 6 Socio-demographic Characteristics of TCFM's Participants (N=93)

Variable		Total	
		N	%
Total		93	100%
Gender	Male	49	53%
	Female	44	47%
Age	18-25	59	63%
	25-35	11	12%
	35-45	3	3%
	45-55	13	14%
	55-65	7	8%
	65 or over	0	0%
Income	Less than 10,000€	10	11%
	10,000€ to 29,999€	20	22%
	30,000€ to 49,999€	12	13%
	50,000€ to 69,999€	37	40%
	70,000€ to 89,999€	6	6%
	90,000€ to 99,999€	3	3%
	100,000€ or more	5	5%
Student	Yes	47	51%
Nationality	Portuguese	60	65%
	German	8	9%
	Italian	19	20%
	Other	6	6%
Qualifications	Less than High School	1	1%
	High School	6	6%
	Bachelor´s Degree	25	27%
	Master's Degree	60	65%
	Doctoral Degree	1	1%
Carbon Footprint	Calculated	10	11%
	Never calculated	83	89%

Appendix 7 Reported Frequencies of Pro-environmental Actions at T1 (N=147)

Regular pro-environmental actions. Please indicate how often you take each action:

	Never	**Sometimes**	**Often**	**Always**	**Total**
Recycle	2%	12%	33%	**52%**	100%
Save water at home	2%	26%	51%	21%	100%
Save energy at home	3%	25%	44%	28%	100%
Use car less	**18%**	26%	36%	20%	100%
Take less leisure flights	**38%**	42%	15%	5%	100%
Avoid eating meat	**36%**	38%	18%	8%	100%
Buy local, seasonal, unprocessed foods	10%	38%	42%	10%	100%

Appendix 8 Believed Usefulness of Actions at T1 (N=147)

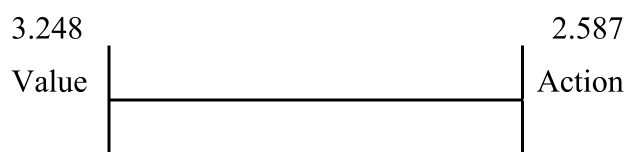
Believed Usefulness of an Action. To what extent would an action ameliorate global warming?

	Would make no difference	**A small impact**	**A medium impact**	**A major impact**	**Total**
Recycle	1%	12%	42%	46%	100%
Save water at home	4%	15%	38%	42%	100%
Save energy at home	0%	18%	43%	39%	100%
Use car less	0%	8%	22%	71%	100%
Take less leisure flights	1%	15%	26%	58%	100%
Avoid eating meat	11%	23%	31%	35%	100%
Buy local, seasonal, unprocessed foods	4%	22%	40%	34%	100%

Appendix 9 Value-Action Gap at T1 (N=147)

Mean values for: Action Frequency and Perceived levels of Effectiveness (Value) of the mitigation options.

	Action	**Value**
Recycle	3.374	3.331
Save water at home	2.895	3.192
Save energy at home	2.960	3.215
Use car less	2.562	3.631
Take less leisure flights	1.847	3.423
Avoid eating meat	1.983	2.908
Buy local, seasonal, unprocessed foods	2.488	3.038
Average	2.587	3.248



Visualization of the Value-Action Gap. Number on the left indicate the mean Value score while the number on the right indicate the mean Action score.

Appendix 10 Correlations between Value and Corresponding Action Statements at T1 (N=147)

	V.recycle	*V.water*	*V.energy*	*V.car*	*V.fly*	*V.meat*	*V.local*	*V.actions*	*A.recycle*	*A.water*	*A.energy*	*A.car*	*A.fly*	*A.meat*	*A.local*	*A.actions*
V.recycle	1															
V.water	0.380**	1														
V.energy	0.340**	0.580**	1													
V.car	0.210**	0.290**	0.250**	1												
V.fly	0.047	0.085	0.230**	0.290**	1											
V.meat	-0.029	-0.24**	-0.160*	0.019	0.110	1										
V.local	0.140	0.150*	0.230**	0.210**	0.280**	0.17948	1									
V.actions	0.440**	0.470**	0.540**	0.450**	0.430**	0.230**	0.530**	1								
A.recycle	**0.002**	-0.014	-0.076	0.027	0.026	0.190*	0.170*	0.093	1							
A.water	0.033	**0.220****	0.14	0.1	0.057	-0.019	0.077	0.110**	0.200*	1						
A.energy	0.062	0.340**	**0.270****	0.15	0.089	0.019	0.096	0.220**	0.290**	0.480**	1					
A.car	0.002	-0.080	-0.072	**0.062**	0.050	0.230**	0.14347	0.110	0.100	-0.014	0.005	1				
A.fly	0.200*	0.180*	0.13	0.14	**0.250****	0.055	0.240**	0.290**	0.110	0.150*	0.180*	0.150*	1			
A.meat	-0.025	-0.022	0.046	0.041	0.230**	**0.402****	0.25585	0.260**	0.170*	0.1	0.088	0.067	0.11	1		
A.local	0.051	0.017	0.064	0.140	0.097	0.031	**0.210****	0.170*	0.230**	0.160*	0.09000	0.150	0.110	0.290**	1	
A.actions	0.071	0.100	0.077	0.150*	0.210**	0.230**	0.300**	**0.298****	0.460**	0.430**	0.430**	0.350**	0.380**	0.440**	0.450**	1

*. Correlation is significant at the 0.05 level (2-tailed).
**. Correlation is significant at the 0.01 level (2-tailed)

Appendix 11 Regression Analyses for PEB Components at T1 (N=130)

	Dependent variable:							
	PEB Score	Recycle	Save water at home	Save energy at home	Use car less	Take less leisure flights	Avoid eating meat	Buy local, seasonal foods
Gender (female)	0.089	0.052	-0.03	0.149	-0.012	-0.026	**0.336****	0.170
	(0.073)	(0.139)	(0.129)	(0.145)	(0.181)	(0.148)	(0.145)	(0.136)
Education	-0.014	0.093	0.079	0.068	-0.104	-0.114	-0.010	-0.157
	(0.051)	(0.099)	(0.091)	(0.101)	(0.126)	(0.104)	(0.102)	(0.096)
Age	0.001	0.0003	0.008	0.007	**-0.022*****	**0.010***	0.008	-0.001
	(0.003)	(0.005)	(0.005)	(0.006)	(0.007)	(0.006)	(0.006)	(0.005)
Income	-0.000	0.000	0.000	-0.000	0.000	-0.000*	-0.000	-0.000
	(0.000)	(0.000)	(0.000)	(0.000)	(0.000)	(0.000)	(0.000)	(0.000)
Environmental Attitudes	0.017	**0.041***	0.033	0.01	0.005	0.003	0.035	0.019
	(0.012)	(0.024)	(0.021)	(0.024)	(0.030)	(0.025)	(0.025)	(0.023)
Nep Score	-0.001	-0.014	**-0.038***	-0.011	0.032	-0.008	0.031	-0.002
	(0.011)	(0.021)	(0.019)	(0.021)	(0.027)	(0.022)	(0.022)	(0.020)
Environmental Concern	**0.157****	**0.198***	**0.218****	0.086	-0.016	0.202	**0.209***	**0.201***
	(0.062)	(0.119)	(0.109)	(0.123)	(0.151)	(0.126)	(0.124)	(0.115)
Carbon Literacy	0.015	0.011	0.001	0.014	0.009	0.004	0.023	**0.044****
	(0.012)	(0.022)	(0.021)	(0.023)	(0.029)	(0.025)	(0.023)	(0.022)
Believed Usefulness of the action	**0.249*****	0.002	**0.224*****	**0.299*****	0.036	**0.205***	**0.319*****	**0.176****
	(0.090)	(0.076)	(0.077)	(0.104)	(0.149)	(0.109)	(0.079)	(0.083)
Constant	0.667	1.532*	1.116	0.975	2.585**	0.851	-1.554**	0.722
	(0.426)	(0.804)	(0.724)	(0.801)	(1.062)	(0.791)	(0.782)	(0.736)
Observations	130	130	130	130	130	130	130	130
R2	**0.284**	**0.102**	**0.167**	**0.133**	**0.104**	**0.135**	**0.338**	**0.203**
Adjusted R2	0.231	0.035	0.105	0.068	0.037	0.070	0.288	0.143
Residual Std. Error	0.393 (df = 120)	0.768 (df = 120)	0.705 (df = 120)	0.783 (df = 120)	0.979 (df = 120)	0.806 (df = 120)	0.793 (df = 120)	0.741 (df = 120)
F Statistic	5.295*** (df = 9; 120)	1.513 (df = 9; 120)	2.679*** (df = 9; 120)	2.044** (df = 9; 120)	1.545 (df = 9; 120)	2.081** (df = 9; 120)	6.811*** (df = 9; 120)	3.398*** (df = 9; 120)

Note: *p<0.1; **p<0.05; ***p<0.01

Appendix 12 Correlations between Carbon Footprint and Socio-demographic Characteristics using Kendall's Tau (N=93)

	Total CF	**Food CF**	**Mobility CF**	**Household CF**
Gender (female)	-0.130	**-0.327****	-0.093	0.041
Age	0.120	0.160	0.095	0.033
Education	**0.180***	0.1	0.160	0.100
Income	**0.190***	**0.168***	**0.150***	-0.024
Nationality (Portuguese)	**0.330****	0.16	**0.310****	0.074
Attitudes	-0.110	-0.130	-0.084	-0.056
Values	-0.019	0.068	-0.014	**-0.160***

*. Correlation is significant at the 0.05 level (2-tailed).
**. Correlation is significant at the 0.01 level (2-tailed)

Appendix 13 Correlations between Carbon Literacy Measures and Carbon Footprint using Kendall's Tau (N=93)

Food specific constructs	**Food Carbon Footprint**
Literacy	**-0.215****
Knowledge	0.013
Motivation	**-0.237****
Ability	**-0.206***
Mobility specific constructs	**Travel Carbon Footprint**
Literacy	**-0.169***
Knowledge	0.135
Motivation	**-0.180***
Ability	**-0.274****
Household specific constructs	**Household Carbon Footprint**
Literacy	0.018
Knowledge	0.086
Motivation	-0.076
Ability	-0.001

*. Correlation is significant at the 0.05 level (2-tailed).
**. Correlation is significant at the 0.01 level (2-tailed)

Appendix 14 Correlations between Carbon Literacy Measures at T1 and at T4 using Kendall's Tau Model (N=93)

Correlation between Literacy measures at T1 using Kendall's tau

	Knowledge	*Motivation*	*Ability*
Knowledge	1.000		
Motivation	**0.177***	1.000	
Ability	**0.188***	**0.092**	1.000

* Correlation is significant at the 0.05 level (2-tailed).
** Correlation is significant at the 0.01 level (2-tailed)

Correlation between Literacy measures at T4 using Kendall's tau

	Knowledge	*Motivation*	*Ability*
Knowledge	1.000		
Motivation	**0.303****	1.000	
Ability	**0.470****	**0.459****	1.000

* Correlation is significant at the 0.05 level (2-tailed).
** Correlation is significant at the 0.01 level (2-tailed)

Appendix 15 Correlations between Changes in Carbon Literacy Constituents and Socio-demographic Characteristics using Kendall's Tau (N=93)

	Knowledge Change	*Motivation Change*	*Ability Change*	*Literacy Change*	*Gender*	*Age*	*Education*	*Income*	*Attitudes*	*Values*
Knowledge Change	1									
Motivation Change	-0.148**	1								
Ability Change	0.207**	0.165**	1							
Literacy Change	0.314**	0.516**	0.632**	1						
Gender	-0.130	-0.003	-0.140	-0.130	1					
Age	-0.030	-0.075	-0.160	-0.140	-0.029	1				
Education	-0.033	0.046	0.0140	0.034	-0.030	-0.061	1			
Income	-0.052	-0.083	-0.100	-0.098	-0.078	0.13	**0.180***	1		
Attitudes	-0.060	**0.211****	-0.086	0.043	**0.218***	0.038	-0.110	-0.088	1	
Values	0.052	**0.239****	0.033	**0.193****	0.0017	0.074	0.0038	-0.041	**0.230****	1

** Correlation is significant at the 0.01 level (2-tailed).
* Correlation is significant at the 0.05 level (2-tailed).

Appendix 16 Action-Intention in Response to Climate Change (N=93)

Pledge	**Carbon Mitigation Impact displayed**	**Pledged to do it**
Food Domain		
Adopt a plant-based diet	H	14.0%
Reduce my meat consumption	H	21.5%
Throw away less food	M	59.1%
Reduce my dairy consumption (milk, yogurts, eggs...)	M	19.4%
Eat more food that is locally in season	L	47.3%
Total		**150**
Average pledges/participant		**1.6**
Mobility domain		
Take fewer flights (excluding business purposes)	H	14.0%
Live car-free (as a driver & passenger)	H	14.0%
Buy/use more energy efficient vehicles	H	30.1%
Use Car Less (as a driver or passenger)	M	31.2%
Drive more economically	L	49.5%
Total		**129**
Average pledges/participant		**1.4**
Household Domain		
Install/Improve insulation products	H	26.9%
Increase recycling	M	49.5%
Better energy management & usage	M	58.1%
Buy energy efficient products	M	53.8%
More responsible water usage	L	67.7%
Total		**238**
Average pledges/participant		**2.6**
Total Pledges		
Mean		5.56
Standard Deviation		3.13
Minimum		0
Maximum		14

Appendix 17 Correlations between Action-Intention and Carbon Literacy and Carbon Footprint, at each Consumption Domain using Kendall's Tau (N=93)

	Food C. Lit	**Food CF**
Pledges (Food related)	0.175*	-0.019
	Mobility C. Lit	**Mobility CF**
Pledges (Mobility related)	0.187*	0.042
	Household C. Lit	**Household CF**
Pledges (Household related)	0.281**	0.002

*. Correlation is significant at the 0.05 level (2-tailed).

**. Correlation is significant at the 0.01 level (2-tailed)