Evidence of ‘Green’ Behaviours: Exploring Behavioural Traces of Pro- and
Anti-Environmental Behaviours

Sabine Topf¹ & Maarten Speekenbrink¹

¹ University College London

Author Note

Department of Experimental Psychology, University College London, London, UK

Department of Experimental Psychology, University College London, London, UK

Declarations of interest: none.

The authors made the following contributions. Sabine Topf: Conceptualization,
Writing - Original Draft Preparation; Maarten Speekenbrink: Writing - Review & Editing.

Correspondence concerning this article should be addressed to Sabine Topf, 26
Bedford Way, London WC1H 0AP, United Kingdom. E-mail: sabine.topf.14@ucl.ac.uk

Abstract

Background. The current climate crisis requires pro-environmental behaviours to be developed, engaged in, and spread to other people. Behavioural traces, i.e. evidence of other people’s pro-environmental behaviour left in the shared environment, have shown to influence people towards being more pro-environmental.

Aims. In a set of three surveys, we investigate which behavioural traces correspond to a number of pro- and anti-environmental behaviours identified from previous literature, how frequently these behavioural traces are encountered, and their relation with engagement in behaviours.

Methods. All studies are survey based with a mix of open-ended questions (Surveys 1 & 3) and rating scales (Survey 2). We use network analysis to identify partial correlations within behaviours and traces, respectively, and between behaviours and traces.

Results. A total of 91 traces uniquely attributed to 51 pro- and anti-environmental behaviours were identified. On average, behavioural traces are encountered monthly, with a range from never to daily. Noticing traces correlated with engaging in related behaviours for the areas ‘Activism’ and ‘Food’, but not ‘Building’, ‘Transport’, ‘Waste’ and ‘Stuff’. Participants report that they expect seeing traces more frequently increases the likelihood of adopting the behaviour that produced them. Finally, participants were generally able to infer the causing behaviours when only presented the traces.

Conclusions. We show that unique behavioural traces exist for the majority of pro- and anti-environmental behaviours. Traces are noticed and relate to the causing behaviours based on correlational and self-report evidence. Because of the wide variation between behaviours and their traces, further research into specific behaviours is warranted. Use of these findings for interventions are discussed.

Keywords: Pro-environmental behaviour, Behavioural traces, Stigmergy, Visibility, Sustainability

Evidence of ‘Green’ Behaviours: Exploring Behavioural Traces of Pro- and Anti-Environmental Behaviours

The current climate crisis requires urgent action to reduce global greenhouse gas emissions and increase protection of the environment (Masson-Delmotte et al., 2018). Along with policy changes, this effort includes increasing individual pro-environmental behaviours. Understanding what makes someone act pro-environmentally is key to this challenge. A pro-environmental behaviour (PEB)¹ is a purposefully chosen action to use fewer resources or emit less greenhouse gases compared to the default (more prevalent or convenient) behaviour (Stern, 2000). A PEB could not just harm less, but benefit the environment (Steg & Vlek, 2009), for instance when planting trees. What constitutes a behaviour as pro-environmental, however, is usually defined by the context and better expressed as degree rather than in absolute terms. If the choice is between public transport and cycling, cycling is more pro-environmental; yet public transport is more pro-environmental compared to driving. Driving, in turn, has less impact than flying (MacKay, 2008).

People are more likely to engage in PEBs if they are aware of the problem and know about possible solutions. A majority of people in Europe and the USA think that the impact of the climate crisis is bad and are worried (Leiserowitz et al., 2019; Poortinga et al., 2018). But even amongst those who are aware and willing, this does not necessarily translate into concrete action (Kollmuss & Agyeman, 2002). In fact, there is a divergence of prevalent and impactful behaviours (Whitmarsh, 2009). One reason for this is a lack of knowledge. The few studies that have looked into objective knowledge show that people do not know about the relative impacts of different actions (Broek, 2019), with knowledge

¹ We use the term “pro-environmental behaviour”; other terms in the literature include “responsible environmental behaviour” (Hines, Hungerford, & Tomera, 1987), “environmentally significant behaviour” (Stern, 2000), “ecological behaviour” (Kaiser, 1998) or “green behaviour” (The British Psychological Society, 2011), amongst others.

barely above chance level (Frick, Kaiser, & Wilson, 2004; Liobikiene & Poškus, 2019). Although more highly educated people are more likely to engage in PEBs, this is because of an increased problem awareness rather than knowledge about the comparative benefit of solutions (Meyer, 2015). How then do people learn about specific PEBs?

One potential route is via behavioural traces. A behavioural trace is evidence of a behaviour left in the shared environment and distinct from direct observation of that behaviour (Topf & Speekenbrink, 2021). There are good reasons why behavioural traces could be instrumental for learning specific behaviours. First, and in contrast to direct communication, behavioural traces do not rely on social signals. People tend to trust information from people more if they resemble them (DeBruine, 2002) or belong to the same group (Brewer, 2008), and even avoid useful information from an out-group source (McDonald & Lohse, n.d.). Since the observation of a behavioural trace is generally divorced from social appearance, one can learn from a wider range of people. Second, behavioural traces can also be more trustworthy than direct communication, especially when created as the mere by-product of a PEB. Unlike “cheap talk”, the traces could not have been created without actually engaging in the behaviour (“sematectonic traces”; Dipple, Raymond, & Docherty, 2014; Marsh & Onof, 2008). Third, agent and observer do not have to be present at the same time for the observer to be able to make an inference about the behaviour. This means that behavioural traces are available for a much longer period than their constituting behaviour, so that even very fleeting behaviours can have an effect long after they took place. Traces can also be witnessed by many more observers, and thus have the potential to influence more people than either direct observation or direct communication could.

A meta-analysis of 84 field-experiments showed an effect of Cohen’s $d = 0.59$, 95% CI [0.52, 0.67], for behavioural traces on behaviour (here: “implicit descriptive norms”; Bergquist, Nilsson, & Schultz, 2019). People are less likely to litter in a clean (vs littered) environment (Cialdini, Reno, & Kallgren, 1990; Keizer, Lindenberg, & Steg, 2013), are

more likely to turn off lights and computers when they initially found the room with those switched off (Bator, Tabanico, Walton, & Schultz, 2014; Bergquist & Nilsson, 2016; Dwyer, Maki, & Rothman, 2015; Oceja & Berenguer, 2009), donate when others have already donated (Jacob, Guéguen, & Boulbry, 2018; Kubo, Shoji, Tsuge, & Kuriyama, 2018; Martin & Randal, 2008; Reingen, 1982), and install solar panels where others have installed them nearby or recently (Baranzini, Carattini, & Péclat, 2017; Bollinger & Gillingham, 2012; Carattini, Levin, & Tavoni, 2019). That behavioural traces have influence on whether people engage in PEBs may be unsurprising, given that engaging in PEBs is a social dilemma. Unless taken often and by many, individual action is effectively meaningless in a global context, however frequent or intense. Engaging in a PEB generally bears some cost to the individual, and future benefits are uncertain and depend on the overall engagement in similar behaviours by the group. This resembles the well-known *Tragedy of the Commons* (Hardin, 1968), for which it has been found that people are more likely to cooperate if they see other people also cooperating. Behavioural traces are one way to know that others are cooperating.

When assessing the impact of behavioural traces, studies so far have only looked at a small set of specific behaviours and not at PEBs in general. The main purpose of the current study is to assess the effect of behavioural traces on a wide variety of PEBs. We aim to answer the following questions: (a) What are common behavioural traces of PEBs?; (b) Do people notice these, and if so, are they interpreted as evidence for the constituting behaviours?; and (c) What is the relation between observing behavioural traces and engaging in PEBs? To do this, we first identify PEBs from the previous literature, followed by obtaining behavioural traces for these (Survey 1). Next, we investigate how frequently these traces are encountered and whether there is any relation between the observation of traces and engaging in pro-environmental behaviours (Survey 2). Finally, we test that the traces generated in Survey 1 are recognised as evidence for the initial pro- and anti-environmental behaviours (Survey 3).

Methods

Identification of pro-environmental behaviours

To identify PEBs and their prevalence, we conducted an extensive literature search. We searched for studies that (a) were from the UK (because behaviours and their traces may differ by country), (b) used quantitative measures, (c) looked at more than one behaviour, (d) had a representative sample due to the methods used, (e) at least 500 participants, and (f) were conducted within the last 10 years (2009-2019). The latter restriction was included under the assumption that prevalence and perceptions of PEBs may have changed rapidly over previous decades (Ballew et al., 2019). This search delivered 289 results. After sighting abstracts for the above criteria, 30 studies remained included. Of these, a further 25 were excluded because they didn't report or measure individual PEBs, were based on existing data, or used unrepresentative samples.

The remaining five studies (1 UK, 3 England, 1 Ireland & Northern Ireland) asked participants to rate how often they engaged in a number of PEBs (see *Table 1*; Whitmarsh, 2009; Huebner, Shipworth, Hamilton, Chalabi, & Oreszczyn, 2016; Lavelle, Rau, & Fahy, 2015; Whitmarsh, Capstick, Nash, & Whitmarsh, 2017; Whitmarsh & O'Neill, 2010). Additionally, we included items from three waves of the Energy and Climate Change Public Attitude Tracker, compiled by the UK Department for Business, Energy and Industrial Strategy (BEIS, 2017), and the UK Survey of Public Attitudes and Behaviours toward the Environment (SABE; DEFRA, 2009). Since the studies used different rating scales or only reported percentages of people already involved in the behaviour, we compiled these in the following way: We transformed prevalence to a 0 (Never / No-one) to 10 (Always / Everyone) scale either by dividing percentage of affirmative responses by 10 or by transforming mean responses $\frac{value-min(scale)}{range(scale)} \times 10$ so that, for instance, a scale with possible responses 0, 1, 2, 3 became 0, 3.3, 6.7, 10. If there was more than one study assessing a behaviour, we report the sample-size weighted mean of the transformed values. In

summary, we identified 62 PEBs from previous literature. We later added items on eating behaviour (e.g., “Eats vegan diet”, “Eats locally grown, in-season food”). These behaviours were not reflected in the previous literature but seemed important with increasing evidence that the way food is produced has a significant impact on the environment.

Table 1

Studies of pro-environmental behaviours included in the analysis.

Study	N	Items	Rating
Whitmarsh (2009)	589	8	% Yes
Whitmarsh & O’Neill (2010)	551	24	Never (0), 5 or more years ago/occasionally (1), 1–3 years ago/often (2), In the last year/always (3)
Lavelle et al. (2015)	1500	10	% Yes
Huebner et al. (2016)	845	4	Never (5), Occasionally (4), Quite often (3), Very often (2), Always (1)
Whitmarsh et al. (2017)	1068	22	Not at all in the past year (1) - At least once a day (10)
DEFRA (2009)	2009	29	% Yes ^{(a)(b)}
BEIS waves 1-21	44141	12 ^(c)	Always - Very often - Quite often - Occasionally - Never ^(b)

Notes: (a) Behaviours were answered on different scales; we counted percentage of people having answered any of the following: Always / Very often / Quite often / I’m already doing this, but probably won’t manage to keep it up / I’m already doing this, though I’d like to do more / I’m already doing this and intend to keep it up / I’ve done this and

intend to do it again / I've already done this. (b) For some of the items, the possible answers also included "Don't know" and "Not applicable". (c) Not all items were included in all waves.

Survey 1 - Generating Behavioural Traces

Survey 1 was conducted to identify possible behavioural traces for all identified PEBs.

Participants. Thirty-nine participants were recruited, as volunteers via word-of-mouth and social media ($N = 21$) as well as from the University College London (UCL) psychology subject pool ($N = 18$).² The latter set of participants were students who received course credit for their participation. The survey had approval from the UCL Research Ethics Committee.

Procedure. In the instructions, the concept of behavioural traces was explained as follows: "A behavioural trace is any physical evidence or artefact of that behaviour, but not the behaviour itself. Note that traces are generally objects but also include noises, smells and digital evidence (e.g., websites)." This definition was followed by examples ("a bike chained to a rail outside your home or workplace"; see *Supplementary Materials* for complete instructions). Next, we asked participants two questions to ensure that they understood the difference between *direct observation of behaviour* ("Seeing someone throw an item in the recycling bin") and *behavioural traces* ("Lights left on in an empty room"). Participants were given feedback and if they answered these comprehension questions incorrectly, they had the chance to revisit the instructions and answer again. Once they passed the comprehension test, participants were shown a random selection of 20 behaviours from a list of 89 behaviours. This list included the behaviours identified from previous literature plus items for the reverse, "anti-environmental" behaviour. For each behaviour, participants could provide as many traces they could think of in a text field

² Demographics were not collected for this survey to keep it brief.

provided. Participants were then thanked and debriefed.

Survey 2 - Frequency of Behaviours and Behavioural Traces

The goal of Survey 2 was to understand how frequently the behavioural traces generated from Survey 1 are observed, and whether there is a relation between observing traces and conducting PEBs.

Participants. In total, 174 participants completed the online survey (Age $M = 20.20$, $SD = 6.25$, 56.32% female). Participants were recruited via prolific.co ($N = 111$), with the remainder via word of mouth, social media and the UCL participant pool. The majority were UK residents (86.21%), and spoke English as their first language (70.69%). Participants received either course credit or payment of £2.00. The survey was approved by the UCL Research Ethics Committee.

Materials. *Traces questionnaire.* This questionnaire included 91 traces identified in Survey 1 (*Supplementary Materials, Table 4*). Participants were asked how often they had noticed the relevant trace in the past three months on a scale from “Never” (1), “Not in the last three months” (2), “Once or twice” (3), “About monthly” (4), “About weekly” (5), “Several times a week” (6), to “About daily” (7).

Behaviours questionnaire. In total, 48 behaviours corresponded to the traces presented above and constituted this questionnaire. Both pro- and anti-environmental behaviours were represented (*Supplementary Materials, Table 3*). Participants were asked how often they typically engage in the behaviour, on a scale from “Never” (1), “Rarely” (2), “Sometimes” (3), “Often” (4), to “Always” (5).

In-/ decrease of behaviour. Participants were asked two open-ended questions asking them when seeing traces made them increase or decrease the frequency of their behaviour: “Please give specific examples of when seeing traces increased (decreased) your own behaviour, i.e., because you saw traces, you did something more (less) often”. They were

also asked two questions about whether they thought that seeing *frequent* traces *less* often, or *infrequent* traces *more* often, would change their behaviour: “From the list of traces, think of traces that you see daily or almost daily. Do you think that if you never saw them again it would change your behaviour?” and “From the list of traces, think of traces that you have never seen before. Do you think that if you suddenly saw them daily it would change your behaviour?”. They were then asked “Would you do the related behaviour...” and could answer with a slider from “less often” (0) to “more often” (100). The slider was set to 50 by default.

Procedure. The survey was hosted on gorilla.sc (Anwyl-Irvine, Massoné, Flitton, Kirkham, & Evershed, 2020). After the aim of the study had been explained, participants were asked for their consent. They then answered the frequency of behaviours and the frequency of traces questionnaires. Order of presentation of the two questionnaires was randomised and counterbalanced. Presentation of items within questionnaires was also randomised. In the last section, participants were asked the open-ended and rating questions about in-/ or decrease of their behaviour. Participants were then thanked and debriefed, after which they had the chance to leave any comments.

Data analysis. A Gaussian Markov random field model (Epskamp, Borsboom, & Fried, 2018) was used to estimate a network of the relations between frequency of (a) behaviours only, (b) traces only, and (c) both behaviours and traces. The network is based on partial polychoric correlations using “least absolute shrinkage and selection operator” (LASSO) regularisation to adjust for the relatively small sample size in comparison with the number of behaviours and traces. This means that the total sum of absolute parameter values is limited. Therefore, some parameters are forced to zero and subsequently drop out of the model. The threshold for this is set through the Extended Bayesian Information Criterion (EBIC) hyperparameter γ . EBIC is typically set between 0 and 0.5, with higher values favouring a more sparse network (Foygel & Drton, 2010). We selected $\gamma = 0.5$ with the goal of obtaining a simple model and minimising the risk of false positives. For three

areas (“Energy”, “Stuff” and “Waste”), this means that the network does not yield any edges. γ would need to be set to .31, .18 and .19, respectively, to produce edges. We omit reporting these networks with reduced γ s as these solutions are likely unreliable. In addition to edges, we report the centrality of behaviours and traces using ‘node strength’, which is calculated by adding the absolute edge weights for that node. This is more reliable than other centrality measures such as betweenness (Epskamp et al., 2018). Finally, the accuracy of the edges and strengths are estimated using non-parametric bootstrapping ($n = 1000$) whereby data are resampled with replacement and confidence intervals of the partial correlations can be calculated (Epskamp et al., 2018). The network analysis is conducted with R packages *bootnet* (Epskamp, Borsboom, & Fried, 2017) and *qgraph* (Epskamp, Cramer, Waldorp, Schmittmann, & Borsboom, 2012), and illustrated using *igraph* (Csardi & Nepusz, 2006).

Survey 3 - Inferring Behaviours From Behavioural Traces

The goal of Survey 3 was to determine whether the traces generated in Survey 1 could be linked back to the original constituting behaviour.

Participants. A total of 35 participants were recruited, with 30 participants from prolific.co. In addition, five psychology undergraduate students who were unaware of the purpose of the study or the initial behaviours, also participated in the survey. All participants were UK residents (62% female, age $M = 38.10$, $SD = 13.16$). Prolific.co participants received £0.15 for participation and a bonus of £0.05 for each meaningful response to open-ended questions. Undergraduate students participated as part of their course requirements. The survey had approval from the UCL Research Ethics Committee.

Materials. From the behavioural traces in Survey 1, we excluded traces (16 items) that did not refer to individual behaviour but rather were either a cumulation of behaviours or mediated by a third party such as “A coal power station (e.g. a cooling tower)” (energy consumption) or response to individual behaviours such as “Bicycle racks

outside school, university, work or shops” (cycling). Traces that referred to labels were also excluded (e.g., “A *suitable for vegans* label on a food product” or “An eco-label on a product”; 9 items). This left 64 traces to be presented.

Procedure. The survey was hosted on Qualtrics (www.qualtrics.com) and presented in two parts. In the first part, a trace, described as “evidence of behaviour”, was displayed one at a time and participants were asked to list up to three realistic behaviours that could have caused this trace. In the second part, the trace was displayed again, this time with the causing behaviour participants had entered in the first part. Then participants were asked to give a realistic reason why someone would engage in this behaviour. The exact wording for the instructions are in *Supplementary Materials*. Participants recruited from prolific.co saw five traces randomly chosen from the pool of traces in the first part and completed both parts. The undergraduate students were presented with the same materials but were presented with 20 (rather than five) randomly chosen behavioural traces and were not asked to complete the second part. All other elements of the survey were the same. Upon completion, all participants were thanked and debriefed.

Data analysis. The open field answers were coded as “*corresponds*” if they matched the behaviour they initially referred to, “*corresponds in principle*” if the participant did not directly mention the behaviour but the idea behind it, or “*does not correspond*” if it referred to an entirely different behaviour. For instance, the behaviour “Uses disposable products (e.g., paper/plastic/styrofoam mugs, food containers, cutlery, ...)” was presented as the trace “A disposable or single-use item such as a paper mug or a plastic take-out container”. A *corresponds* answer might be “Someone has purchased a take-away coffee from a coffee shop”, a *does not correspond* answer might be “The container could have been re-used and washed up”, and an answer that *corresponds in principle* might be “A demand was created for a take-away item”. The first author rated all items; a group of five additional raters categorised a fifth of the items each. There was

disagreement in 46.40% cases; this is a combination of 6.90% cases where one rater said “*corresponds*” and the other “*does not correspond*”, 16.80% cases where one said it “*corresponds*” and the other that it “*corresponds in principle*”, and 21.60% cases where one said it “*does not correspond*” and the other it “*corresponds in principle*”. Where there were discrepancies in the rating, the remaining four raters voted independently for one of the two ratings. Most cases were resolved this way with 8.60% that could not be agreed upon; these were excluded from analysis.

Reasons generated for the behaviours were rated by both authors. A coding scheme was devised for external (physical, social, chance) and internal (altruism, self-interest, cognition, emotions) reasons, inspired by previous literature (Kollmuss & Agyeman, 2002; Li, Zhao, Ma, Shao, & Zhang, 2019). Subthemes were recorded as they emerged from the data by the first author and employed during coding by the second author. If several reasons were given, only the first was recorded (e.g., “It’s cheaper/healthier/better for the environment than bus/car”). Agreement rate between first and second rater was at 88.50%. Where there was disagreement, four additional raters voted independently for one of the two ratings which left 3.40% of reasons where no coding could be agreed upon; again, these were not included in the analysis.

Results

Frequency of behaviours

Out of the 89 behaviours (pro- and anti-environmental) presented in Survey 2, the three reported as most frequently performed were “Eat a hot meal (R)”, $M = 4.20$, $SD = 4.17$, “Recycle items that can be recycled (e.g., glass, paper, plastic, aluminium)”, $M = 4.10$, $SD = 4.11$, and “Try not to waste food (e.g. by using leftovers)”, $M = 4$, $SD = 3.99$; the three least frequently performed behaviours were “Drive an electric car”, $M = 1.20$, $SD = 1.18$, “Discourage other people from being more pro-environmental (R)”, $M = 1.40$, SD

= 1.37, and “Cycle to school, university or work”, $M = 1.60$, $SD = 1.61$. All behaviours and mean frequencies are presented in *Supplementary Materials, Table 3*. Frequency of behaviours in the current study correlated positively with the sample-weighted frequency of previous studies, $r(41) = 0.58$, $p < .001$.

Identification of behavioural traces

Each of the 89 behaviours (pro- and anti-environmental) was presented on average to 10.80 participants (min = 7, max = 15) in Survey 1. Participants generated a total of 440 traces, or on average 5.24 traces per behaviour (min = 1, max = 13; pro- and anti-environmental behaviours counted separately).

Traces were excluded from the set presented in Survey 2 if they were exact duplicates (27 responses) or very similar to a trace for a different PEB and thus ambiguous (23) or ambiguous in terms of how many other behaviours not included in the study could have caused it (e.g., “A blanket draped over the sofa in someone else’s house” as a trace for the behaviour “Bought or built a traditional home”; 50). Traces were also excluded if they tended to be too private (e.g., “A high energy bill”; 68) or otherwise hard to know about (e.g., “Items past sell-by date in a shared fridge / shared pantry”; 59). Traces mediated by a third party in response to other’s behaviour (e.g., “Meat options in restaurants and cafes”, 37) were also excluded. This procedure reduced the number of unique traces presented in Survey 2 to 88. Behaviours and the numbers of associated traces generated in Survey 1 (plus reasons for exclusions) can be found in the *Supplementary Materials*. In the final list, 51 of the initial behaviours had at least one unique trace. Most of these behaviours were linked to only one unique trace (median = 1, min = 1, max = 5). The item with the most traces was “Cycles for journeys of less than 3 miles” (5 traces), followed by “Bought or built an energy-efficient home (e.g. passive house)” and “Takes train or car for holidays or leisure trips instead of flying (this excludes travelling for work)” (4 traces each).

Frequency of trace encounters

The three traces reported as most frequently observed (Survey 2) were “A car parked outside school, university, work or shops (R)”, $M = 6.20$, $SD = 6.22$, “A sign for public transport (e.g., for tube entrance, train station, bus stops)”, $M = 6$, $SD = 5.98$, and “A re-usable item such as a mug/cup, water bottle, lunch container, fabric bag”, $M = 5.90$, $SD = 5.85$. The three traces reported as observed least frequently were “A new petrol station opening (R)”, $M = 2$, $SD = 2.04$, “That a petrol station closed down”, $M = 2.10$, $SD = 2.09$, and “A coal power station (e.g. a cooling tower) (R)”, $M = 2.20$, $SD = 2.23$. All traces and mean frequencies are presented in *Supplementary Materials, Table 4*.

Co-occurrence of behaviours

We used network analysis to determine whether some behaviours are more likely to be performed if others are also performed. The resulting partial correlations network of behaviours is visualised in *Figure 1*. The solution shows seven clusters of behaviours which are related to each other, but not to behaviours of other clusters.

Three clusters relate to transport. Mode of transport for commuting correlates with mode of transport for errands. The strongest relation is between “Cycle to school, university or work” (CycleWork) and “Cycle for shopping and other errands” (CycleShop), $r(167) = .40$, 95% confidence interval [.29, .52], followed by “Walk to school, university or work” (WalkWork) and “Walk for shopping and other errands” (WalkShop), $r(167) = .27$ [.17, .37], “Cycle to school, university or work” and “Drive to get to school, university or work (R)” (DriveWork) and “Drive for shopping and other errands (R)” (DriveShop), $r(167) = .27$ [.16, .38], as well as “Take public transport to get to school, university or work” (PubTransWork) and “Take public transport for shopping and other errands” (PubTransShop) $r(167) = .17$ [.02, .32]; meaning that people are likely to use the same mode of transport for commuting as well as everyday errands. Those who “Walk” are also

unlikely to “Drive” (r s of $-.09$ $[-.20, .01]$, $-.14$ $[-.23, -.04]$, and $-.13$ $[-.24, -.02]$, respectively).

Another cluster reflects food where “Eat a meat-free (vegetarian) meal” is positively correlated with “Eat a meat-free, egg-free and dairy-free (vegan) meal”, $r(167) = .29$ $[.20, .38]$. Both correlate negatively with “Eat a meal that includes meat (R)” with r s of $-.09$ $[-.20, .01]$, and $-.23$ $[-.36, -.11]$, respectively.

Additionally, there is a small cluster of behaviours around activism-related items such as “Donate or invest money in a pro-environmental project” (Donate), “Take part in a campaign or protest about an environmental issue” (Campaign), and “Do something together with others to address an environmental issue (e.g., set up recycling scheme)” (EnviroScheme), with positive partial correlations of r s = $.14$ $[.02, .25]$, $.13$ $[.02, .25]$, and $.14$ $[.02, .26]$, respectively.

Further, “Shop or order things online” (ShopOnline) correlates positively with “Buy a new item (e.g., clothes, luxury items) (R)” (NewItems), $r(167) = .21$ $[.09, .33]$. Also people who “Install a more efficient heating system” (HeatingSystem) are more likely to also “Install additional insulation in your home” (Insulation), $.14$ $[.01, .27]$. People who “Eat locally grown, in-season food” (LocalSeasonFood) are also more likely to “Eat organic food” (OrganicFood), $.13$ $[.00, .26]$, *et vice versa*. For all other partial correlations, the bootstrapped confidence interval includes zero.

Relations between observations of traces

The partial correlations network of traces for pro-environmental behaviours (light yellow nodes) and for anti-environmental behaviours (dark yellow nodes) is visualised in *Figure 2*. The solution shows eight clusters of traces.

The largest correlation can be found between noticing “A solar panel on someone’s house” (SolarPanel) and “A solar heating panel on someone’s house” (SolarHeating), $r(165) = .23$ $[.08, .38]$, followed by “Social media posts about or likes of articles about

Figure 1. Correlation network of pro-environmental (light green) and anti-environmental behaviours (dark green). Pictured are positive (blue edges) and negative partial correlations (red edges). Nodes are placed close to each other when there is a significant correlation, otherwise placement is random. Behaviours without significant correlations to any other behaviours were excluded from this graph.

sustainability and climate change” (SocMediaArticle) and “Social media posts about or likes of a pro-environmental project or campaign” (SocMediaCampaign), $r(165) = .19$ [.06, .33]. People who notice the trace “Bicycle racks outside school, university, work or shops” (BikeRack) are more likely to also notice “A bicycle parked outside school, university, work or shops” (BikeParked), $r(165) = .14$ [.01, .26]; and people who notice the trace “A high energy-efficiency rating on real estate information” (HighEffRating) are more likely to also notice “A low energy-efficiency rating on real estate information (R)” (LowEffRating),

387 $r(165) = .14 [.01, .26]$. For all other partial correlations, the bootstrapped confidence
 388 interval includes zero.

Figure 2. Correlation network of pro-environmental (light yellow) and anti-environmental traces (dark yellow). Pictured are positive (blue edges) and negative partial correlations (red edges). Nodes are placed close to each other when there is a significant correlation, otherwise placement is random. Behaviours without significant correlations to any other behaviours were excluded from this graph.

389 Relations between behaviour and observation of traces

390 Partial correlations networks of behaviours (green nodes) and traces (yellow nodes)
 391 are visualised in *Figures 3 - 6*. The networks relate to “Activism”, “Food”, “Buildings” and
 392 “Transport”. Items related to “Energy”, “Stuff” and “Waste” had no edges and are

therefore not visualised. The solution shows two large clusters of behaviours and traces for “Activism” and “Food”, and several smaller clusters for “Buildings” and “Transport”.

The largest cluster contains behaviours and traces related to “Activism” (*Figure 3*). People who notice “Torn-up flyers about a pro-environmental campaign (R)” (TornFlyer) are more likely to engage in the behaviour “Discourage other people from being more pro-environmental (R)” (Discourage), with $r(175) = .15 [.00, .29]$. Those who notice “Social media posts about or likes of articles about sustainability and climate change” (SocMediaArticle) are likely to “Educate yourself about topics related to sustainability and climate change” (Learn), $r(175) = .17 [.05, .29]$, as are those who notice “Signatures already on a petition list for a pro-environmental issue (online or on paper)” (PetitionSign), $r(175) = .13 [.02, .23]$. People who notice “Donations to pro-environmental projects or organisations on a crowdfunding website” (Donations) are likely to “Donate or invest money in a pro-environmental project” (Donate), $r(175) = .12 [.01, .24]$. Note that these are partial correlations which provide no basis to determine the causal direction from behaviour to traces or from traces to behaviours.

A second large cluster contains items related to “Food” (*Figure 4*). People who notice An “organic product” label on food (OrganicLabel) more likely “Eat organic food” (OrganicFood), $r(175) = .16 [.02, .30]$. Also, people who notice “A ‘suitable for vegetarians’ label on a product” (SuitVeg) are more likely to “Eat a meat-free (vegetarian) meal” (Vegetarian), $r(175) = .24 [.13, .34]$.

In the clusters “Buildings” (*Figure 5*) and “Transport” (*Figure 6*) there are no links between traces and behaviours.

Figures 7 - 10 show *node strength* and their 95% confidence intervals as a measure of centrality for the four networks. High centrality means that these nodes are well connected with other behaviours and traces — if a person engages in this behaviour or sees that trace, they are also more likely to engage in other behaviours. Nodes of high centrality

Figure 3. Correlation network of behaviours (green) and traces (yellow) for items related to “Activism”. Behaviours (green nodes) and traces (yellow nodes) with their respective positive (blue edges) and negative partial correlations (red edges). Nodes are placed close to each other when there is a significant correlation, otherwise placement is random. See Tables 2 and 3 for items.

could therefore be leverage points for interventions, in order to increase overall pro-environmental engagement. There is a tendency for both pro-environmental traces and behaviours having higher centrality than anti-environmental traces and behaviours. However, only eating vegetarian meals has a significantly higher strength within the network than most of the other food related behaviours and nodes. This could be an indication that following a vegetarian diet leads to noticing more of the related traces and perhaps increases the chances of also eating local, seasonal and organic or vegan food.

Figure 4. Correlation network of behaviours (green) and traces (yellow) for items related to “Food”. Behaviours (green nodes) and traces (yellow nodes) with their respective positive (blue edges) and negative partial correlations (red edges). Nodes are placed close to each other when there is a significant correlation, otherwise placement is random. See Tables 2 and 3 for items.

In/decrease of frequency of behaviour based on seeing traces. On average, participants reported that if they never saw a currently frequent trace again, it would likely not affect their behaviour, $M = 48.20$, $SD = 23.99$; on a scale from 0 - less often to 100 - more often). However, if they were to see a currently infrequent trace daily in the future, participants reported they would likely engage in the related behaviour more often, $M = 59.60$, $SD = 22.81$.

When asked about a specific example of when seeing a trace actually decreased or

Figure 5. Correlation network of behaviours (green) and traces (yellow) for items related to “Buildings”. Behaviours (green nodes) and traces (yellow nodes) with their respective positive (blue edges) and negative partial correlations (red edges). Nodes are placed close to each other when there is a significant correlation, otherwise placement is random. See Tables 2 and 3 for items.

increased their behaviour, the most frequently mentioned trace was “News, article or film about plastic in the environment (e.g., oceans)” with 16 mentions. This influenced a number of behaviours, including “Use reusable shopping bag/Avoid single-use plastic bags” (6 mentions), “Recycle more” (4), “Use reusable products/Avoid disposable products” (4), “Avoid plastics” (1), and specifically “Use reusable water bottle” (1). The second most frequent traces were “Dedicated recycling bins” and “Littering”, both with 14 mentions, respectively. The former trace led to “Recycle more” (14). The latter trace mainly meant

Figure 6. Correlation network of behaviours (green) and traces (yellow) for items related to “Transport”. Behaviours (green nodes) and traces (yellow nodes) with their respective positive (blue edges) and negative partial correlations (red edges). Nodes are placed close to each other when there is a significant correlation, otherwise placement is random. See Tables 2 and 3 for a description of the items.

that people “Don’t litter” (8), “Avoid disposable cups/Avoid plastics/Avoid single-use plastic bags/Use reusable water bottle” (4) and finally also “Recycle more” (2). Also often reported are the traces “Lights on” (11) and “Reusable shopping bag” (11).

The behaviour reported most frequently as having de-/increased, “Recycle more” (35), is mainly triggered by the presence of “Dedicated recycling bins” (14). The second most frequently reported item, “Turn off lights” (18), is mainly caused by “Lights on” (11) but also by “Lights off (1)”.

Figure 7. Centrality (node strength) for all behaviours and traces in the “Activism” network, with 95% confidence intervals.

Figure 8. Centrality (node strength) for all behaviours and traces in the “Building” network, with 95% confidence intervals.

Figure 9. Centrality (node strength) for all behaviours and traces in the “Food” network, with 95% confidence intervals.

Figure 10. Centrality (node strength) for all behaviours and traces in the “Transport” network, with 95% confidence intervals.

In general, a behaviour was more likely to *increase* (61.74%) than decrease (38.26%) if the trace was pro-environmental. But when the trace was anti-environmental, the related behaviour is more likely to decrease (65.71%) than increase (34.29%). This difference between de-/increase of behaviour and type of trace is significant, $\chi^2(1) = 12.05$, $p = .001$, showing that trace and behaviour are aligned: More pro-environmental traces mean an increase in pro-environmental behaviours, more anti-environmental traces mean a decrease in pro-environmental behaviours.

Inference of behaviours from traces

In Survey 3, participants provided 524 possible causing behaviours for the traces presented to them. Of those, 20 were only one-word responses or short phrases that did not clearly refer to a behaviour and were thus excluded. Although we aimed to obtain an equal number of responses for all traces, this was complicated by the fact that some people returned the survey unanswered and participants were not required to answer all (or even any) items. Each trace received between 4 and 11 responses.

Of all responses, 130 (24.80%) were rated as “*corresponds*” to the behaviour, 142 (27.10%) were rated as “*corresponds in principle*”, and 207 (39.50%) were classified as “*does not correspond*”. Although all behaviours were coded as “*corresponds in principle*” at least once, a total of 14 traces had no behaviour that was rated as “*corresponds*”. Two traces were always recognised as produced by the initial behaviour, these were “Double or treble glazed windows in someone’s home” and “An appliance that is unplugged when not in use (e.g. stand-by light is off, room is quiet)”. Full results can be found in the *Supplementary Materials*.

As expected, the order of the answers mattered. In a multinomial logistic regression that uses “*does not correspond*” as the baseline category, both “*corresponds*”, $z = 6.38$, $p < .001$, and “*corresponds in principle*”, $z = 4.46$, $p < .001$, were more likely than “*does not*

correspond” as the first answer compared to the remaining answers. They are, however, no more likely than “*does not correspond*” as the second compared with the third answer, with $z = 0.57$, $p = .569$ for “*corresponds*” and $z = 1.62$, $p = .106$ for “*corresponds in principle*”, respectively. This means that the original behaviour is likely to be the first that comes to mind, compared to possible alternative behaviours.

Inference of reasons for behaviours from traces

Participants reported 139 reasons for why the behaviours they inferred from the traces were performed. We analysed only the 87 reasons for behaviours rated as “*corresponds*” or “*corresponds in principle*”. Table 2 lists the frequency of themes and sub-themes for external and internal reasons, respectively. Internal reasons are mentioned more often (79.31%) than external reasons (17.20%). Overall, the most frequent reason is “Altruism: Benefit climate / environment” (21.80%), followed by “Self-interest: Money saving” (20.70%), with a shared third place for “Self-interest: Convenience / avoid effort” and “Self-interest: Enjoyment” (6.90% each). A closer look shows that all “Benefit climate / environment” were in response to pro-environmental behaviours (100%). “Money saving”, in contrast, was given as a reason for both pro- (29.30%) and anti-environmental behaviours (13.80%).

Discussion

In Survey 1 participants generated on average one behavioural trace for each of the previously identified PEBs. Thirty-seven behaviours had no unique, unambiguous trace. The results suggest that just as some PEBs are more visible than others (Brick, Sherman, & Kim, 2017), there are also differences in the visibility of behavioural traces. Future research could investigate whether there is a link between the visibility of traces and the likelihood of people engaging in the related PEBs, i.e. whether people decide to (not) engage in PEBs

Table 2

Motivations/reasons for behaviours generated

Area	Theme	Subtheme	Frequency
External	Circumstances / chance		7
		Physical	
		Design of item or environment	4
	Social	Time constraints	1
		Regulations	3
Internal	Altruism	Benefit climate / environment	19
		Benefit other people	2
	Cognition	Forgetful / not paying attention	4
		Learning	1
		Self perception	1
		Wants to communicate	1
	Emotion	Anger	4
		Worry / concern	1
	Physical	Design of item or environment	1
	Self-interest	Money saving	18
		Convenience / avoid effort	6
		Enjoyment	6
		Convenience/avoid effort	3
		Health	2

based on whether their own traces are visible, as has been found for the visibility of PEBs themselves (Brick et al., 2017; Griskevicius, Tybur, & Van den Bergh, 2010).

In Survey 2 we looked at the frequency of individuals' engagement in pro- (and anti-) environmental behaviours, the frequency of noticing related behavioural traces, and finally the relation between engaging in behaviours and observing traces. Comparable to the previous literature, there is a wide range of engagement in different PEBs. Also as in previous studies, there is a negative relation between the frequency and impact of behaviours (see *Supplementary Materials*; Whitmarsh, 2009), albeit a less strong one than reported previously. A possible explanation could be that since the latest prior study was published in 2017, knowledge has increased in the population and more impactful behaviours have since been adopted. However, even in 2019, knowledge about the impact of PEBs is barely above chance level (Broek, 2019; Liobikiene & Poškus, 2019). Another possible explanation is that we had a less representative and more pro-environmental sample. This is also supported by the fact that although prevalence of PEBs in the current study with previous studies correlates positively and significantly, there is far from a perfect match.

Not previously investigated, there is substantial variability in whether behavioural traces are noticed, ranging between daily to having never been noticed before. The patterns of relations between behaviours and traces determined in the network analyses make intuitive sense. For instance, travel, shopping and eating habits correlate positively if they are both pro- or both anti-environmental but negatively if they are opposites. There are relations between encountering a trace and engaging in a related behaviour for the areas "Activism" and "Food". Other relations that could be expected from the literature were not found, e.g. a connection between pro-environmental travel and diet options (Smith, Böhnke, Graham, White, & Prady, 2016). Finally, according to participants' reports, a PEB was more likely to *increase* with noticing a pro-environmental trace and more likely to decrease if the trace was anti-environmental.

There are four interesting results to highlight from Survey 2. Firstly, “Shop or order things online” correlates positively with “Buy a new item (e.g., clothes, luxury items)”, $r(167) = .21$. This suggests that online shopping should not be classified as a pro-environmental behaviour. Initially it was thought that emissions are limited if online shopping replaces someone driving to the shops for just this one item. However, it has since become clear that online shopping can be worse, especially when express/next day delivery replaces more environmentally-friendly ways of transport (Weideli, 2013).

Secondly, there were no correlations between frequent behaviours that tend to be relatively easy, such as recycling, washing clothes at 30°C, or boiling only as much water as needed. On the other hand, more difficult or “committed” behaviours (e.g., donate, campaign, substantial changes to one’s home) are correlated. Perhaps this means that behavioural “positive spillover” (i.e., an increased likelihood of engaging in one PEB after having engaged in another; Thøgersen, 2012) only occurs if there is a certain level of commitment or self-identification as “a green person”. Previous findings on positive spillover for PEBs are mixed (Nash et al., 2017). Potential pathways for positive spillover could be that PEBs (a) serve a common goal; (b) influence someone towards a “greener” self-perception; (c) cause cognitive dissonance; or (d) increase learning about environmental issues. In line with this, it is possible that relatively frequent behaviours such as recycling have lost the power to constitute self-identity compared to ten years ago (Nigbur, Lyons, & Uzzell, 2010) or in a different population. But the question remains why a person starts with one of the “committed” behaviours in the first place. The only item that has significantly higher centrality than other behaviours or traces in the “Food” network is “Eat a meat-free (vegetarian) meal”, which may indicate that this is an “entry behaviour” from which other behaviours (such as following a vegan diet, eating locally-grown or organic food) follow. The results of our network analysis are intentionally very conservative estimates, and future research with a smaller set of behaviours or a larger sample size could further shed light on this possibility.

Thirdly, the second most frequently reported behaviour “Turn off lights” , is mainly caused by “Lights on” but also by “Lights off”. This is in contrast to previous studies that looked at how likely it is that people leave the lights on or off depending on whether they were on or off before entering a room (Bergquist & Nilsson, 2016; Dwyer et al., 2015; Ocejja & Berenguer, 2009). Here the opposite is reported: Lights that are left on prompt participants to switch them off. This may indicate that people are not always aware of when or how they are influenced by behavioural traces. Perception of behavioural traces may be “more automatized . . . and thus result in corresponding behaviors with less conscious processing” (Bergquist et al., 2019).

Finally, all partial correlations between traces were positive. In other words, noticing any trace (either pro- or anti-environmental) makes it more likely to notice other traces. This could be an effect of individual differences in attention: There is considerable and significant variation between individuals with regards to whether moving/touched objects are attended to (De Haas, Iakovidis, Schwarzkopf, & Gegenfurtner, 2019), with the implication that some people may be more prone to attend to behavioural traces than others. Again, people may not be aware of this tendency. This lack of awareness is not necessarily a “bad” thing: For one, not having to actively seek and perceive traces may be an advantage to coordinate more effortlessly (Parunak, 2005). Also, reactions to behavioural traces may be “driven by nonconscious imitation” and are therefore “less susceptible to anti-conformity and reactance” because “people are less likely to identify a sender” (Bergquist et al., 2019, p. 3). As one participant wrote: “if [I] see people [I] dislike doing something, it makes me much less likely to do it myself”. Traces are generally divorced from social appearance; they do not carry the type of information enabling the observer to decide whether one likes or dislikes the person causing it. Behavioural traces are thus arguably more trustworthy than direct communication, especially when created as a by-product of a PEB (so-called *sematectonic traces*; Dipple et al., 2014; Marsh & Onof, 2008).

In Survey 3 all behaviours could at least in principle be inferred from the presented behavioural traces. As expected, “*corresponds*” and “*corresponds in principle*” ratings were more frequent than “*does not correspond*” among first responses compared to second and third responses. However, we do not know *how strongly* people endorsed the behaviours they generated. Another study could follow up on this, presenting the trace and letting people rate various possible behaviours (including the original behaviour and behaviours generated from this survey alongside decoys). Interestingly, despite 61.40% of the original behaviours being pro-environmental, only 21.84% of the behaviours generated were explained through a motivation to protect the environment. That is, although people could generally infer the behaviour from the trace, they did not always infer pro- (or anti-) environmental motives as being behind the behaviour. In the absence of knowledge about the actor, people may project their own motives onto others (Malle, 2011). If this is the case, self-interested benefits such as “money saving” are an important motivator behind PEBs in our sample. Self-interest and altruism can both increase the motivation to engage in PEBs depending on individual motives and may thus be complementary pathways to increased PEBs (De Dominicis, Schultz, & Bonaiuto, 2017).

To the best of our knowledge, this is the first study to comprehensively investigate behavioural traces for a large number of PEBs. We showed that behavioural traces exist for a wide range of pro- and anti-environmental behaviours and people are generally able to infer the causing behaviour when presented with the trace. Many of the traces are encountered within the last three months, and on average monthly. Noticing certain traces made people more likely to notice other traces as well. There are positive relations between encountering a trace and engaging in a related behaviour for the areas “Activism” and “Food” so that noticing a trace increases the likelihood of the behaviour occurring *et vice versa*.

Future directions. There are a number of limitations to the present study. Firstly, the design of the study does not allow us to draw conclusions about causality. People may

already be engaging in the behaviour and as a result encounter other people's traces more often; or, participants may encounter other's traces and therefore explore the behaviour. When asked about their own estimation whether traces would decrease or increase their behaviours, they expect seeing a new trace to increase the related behaviour. By contrast, once a behaviour is adopted, they expect that seeing the related trace never again would have little impact. This indicates that behavioural traces may be a source of learning new behaviours, but have little impact on the maintenance of that behaviour. Most likely, the relation between traces and behaviour is a dynamic one that depends on a number of other factors, such as the *frequency*, *number* and *type* of traces encountered (Topf & Speekenbrink, 2021). Someone not currently engaging in a behaviour may become aware of the behaviour through traces that are frequent, numerous, or otherwise highly salient. As they start engaging in the behaviour, they would likely encounter related traces even more often, for instance if they start commuting by bicycle and therefore encounter more cycling-related traces. Whilst this is plausible, additional research is required to ascertain the direction of this relation, ideally longitudinally. Future research could focus on specific behaviours and their trace in a more controlled design to shed light on the causal direction between traces and behaviours. Since this study focused on traces in the UK, understanding what behaviours link to which traces would need to be repeated in different contexts.

Secondly, the sample size of Survey 2 is relatively small for the number of items (behaviours and traces) assessed. As we only report substantial effect sizes, the results are conservative and should not include many false positives. A follow-up study with a larger, more representative sample would be desirable, and may be able to detect more subtle relations.

Thirdly, many studies regarding PEBs—including the present—rely on self-report measures. These are not entirely reliable—only 79% of variance in actual behaviour is explained by self-report measures (Kormos & Gifford, 2014). Also, people may

overestimate how pro-environmentally they behave compared to others (Bergquist, 2020). Similarly, people may not be able to accurately report behavioural traces encountered if the measure is, for instance, not immediate and sensitive enough (Newell & Shanks, 2014). It is therefore desirable to use actual behaviour as the outcome measure in future research and, where possible, manipulate or control for features of behavioural traces.

Conclusion. Widespread adoption of PEBs will be necessary to avert the worst of the climate crisis (Dietz, Gardner, Gilligan, Stern, & Vandenberg, 2009), be that voluntary as bottom-up action or through policy changes as top-down requirements. Most likely, new policies will be adopted more quickly if they are introduced when a critical number of people already engage in related behaviours. The near global ban or tax on single-use plastic bags is a case in point (Clapp & Swanston, 2009). The results of this study imply that in terms of interventions, a two-pronged approach is promising: (1) encourage those who already engage in PEBs, and (2) visually highlight or otherwise emphasize the resultant behavioural traces while (3) making anti-environmental traces less salient. Together, this would directly and indirectly increase awareness of the behaviours as well as the number of people engaged in these behaviours. In turn, necessary policy changes will be more acceptable to the general public. While more research is needed to fully understand the relation between behaviours and their traces, making beneficial traces more salient (and detrimental ones less so) is a relatively easy and low-cost intervention that could complement existing efforts to increase pro-environmental behaviours throughout the population.

References

- Anglian Water. (n.d.). *Using water at home*. Retrieved from https://www.anglianwater.co.uk/%7B/_%7Dassets/media/Fact%7B/_%7DFile%7B/_%7D5%7B/_%7D-%7B/_%7DUsing%7B/_%7Dwater%7B/_%7Dat%7B/_%7Dhome.pdf
- Anwyl-Irvine, A. L., Massoné, J., Flitton, A., Kirkham, N. Z., & Evershed, J. K. (2020). Gorilla in our midst: an online behavioural experiment builder. *Behavior Research Methods*, 52, 388–407. <https://doi.org/10.3758/s13428-019-01237-x>
- Automobile Association. (n.d.). *Save fuel and money with eco-driving*. Retrieved from <http://www.theaa.com/driving-advice/fuels-environment/drive-smart>
- Ballew, M. T., Leiserowitz, A., Roser-Renouf, C., Rosenthal, S. A., Kotcher, J. E., Marlon, J. R., ... Maibach, E. W. (2019). Climate Change in the American Mind: Data, tools, and trends. *Environment: Science and Policy for Sustainable Development*, 61(3), 4–18. <https://doi.org/10.1080/00139157.2019.1589300>
- Baranzini, A., Carattini, S., & Péclat, M. (2017). *Social contagion in the adoption of solar photovoltaic technology: New evidence from Switzerland* (p. 36). "Grantham Research Institute on Climate Change; the Environment". Retrieved from <https://www.lse.ac.uk/granthaminstitute/wp-content/uploads/2017/07/Working-Paper-270-Barranzini-et-al.pdf>
- Bator, R. J., Tabanico, J. J., Walton, M. L., & Schultz, P. W. (2014). Promoting energy conservation with implied norms and explicit messages. *Social Influence*, 9(1), 69–82. <https://doi.org/10.1080/15534510.2013.778213>
- BBC. (2011). *People's showering habits revealed in survey*. Retrieved from <https://www.bbc.com/news/science-environment-15836433>
- BEIS. (2017). *Energy and Climate Change Public Attitudes Tracker, Wave 21* (p. 19).
- Bergquist, M. (2020). Most People Think They Are More Pro-Environmental than Others:

A Demonstration of the Better-than-Average Effect in Perceived Pro-Environmental Behavioral Engagement. *Basic and Applied Social Psychology*.
<https://doi.org/10.1080/01973533.2019.1689364>

Bergquist, M., & Nilsson, A. (2016). I saw the sign: Promoting energy conservation via normative prompts. *Journal of Environmental Psychology*.
<https://doi.org/10.1016/j.jenvp.2016.03.005>

Bergquist, M., Nilsson, A., & Schultz, W. P. (2019). A meta-analysis of field-experiments using social norms to promote pro-environmental behaviors. *Global Environmental Change*, 59(November), 101941. <https://doi.org/10.1016/j.gloenvcha.2019.101941>

BIO Intelligence Service. (2011). *Assessment of impacts of options to reduce the use of single-use plastic carrier bags. Final Report prepared for the European Commission – DG Environment*. Retrieved from https://ec.europa.eu/environment/waste/packaging/pdf/report%7B/_%7Doptions.pdf

Bollinger, B., & Gillingham, K. (2012). Peer Effects in the Diffusion of Solar Photovoltaic Panels. *Marketing Science*, 31(6), 900–912. <https://doi.org/10.1287/mksc.1120.0727>

Brewer, M. B. (2008). Depersonalized trust and ingroup cooperation. In *Rationality and social responsibility: Essays in honor of robyn mason dawes*.
<https://doi.org/10.4324/9780203889695>

Brick, C., Sherman, D. K., & Kim, H. S. (2017). "Green to be seen" and "brown to keep down": Visibility moderates the effect of identity on pro-environmental behavior. *Journal of Environmental Psychology*, 51, 226–238.
<https://doi.org/10.1016/j.jenvp.2017.04.004>

Broek, K. L. van den. (2019). Household energy literacy: A critical review and a conceptual typology. *Energy Research and Social Science*, 57(August), 101256.
<https://doi.org/10.1016/j.erss.2019.101256>

- Carattini, S., Levin, S., & Tavoni, A. (2019). Cooperation in the climate commons. *Review of Environmental Economics and Policy*, 13(2), 227–247.
<https://doi.org/10.1093/reep/rez009>
- Cialdini, R. B., Reno, R. R., & Kallgren, C. (1990). A Focus Theory of Normative Conduct: Recycling the Concept of Norms to Reduce Littering in Public Places. *Journal of Personality and Social Psychology*, 58(6), 1015–1026.
<https://doi.org/10.1037/0022-3514.58.6.1015>
- Civil Aviation Authority. (2016). *Domestic Terminal Passenger Traffic*. Retrieved from https://www.caa.co.uk/uploadedFiles/CAA/Content/Standard%7B/_%7DContent/Data%7B/_%7Dand%7B/_%7Danalysis/Datasets/Airport%7B/_%7Dstats/Airport%7B/_%7Ddata%7B/_%7D2016%7B/_%7Dannual/Table%7B/_%7D10%7B/_%7D2%7B/_%7DDomestic%7B/_%7DTerminal%7B/_%7DPassenger%7B/_%7DTraffic.pdf
- Clapp, J., & Swanston, L. (2009). Doing away with plastic shopping bags: International patterns of norm emergence and policy implementation. *Environmental Politics*, 18(3), 315–332. <https://doi.org/10.1080/09644010902823717>
- Csardi, G., & Nepusz, T. (2006). The igraph software package for complex network research. *InterJournal, Complex Systems*, 1695. Retrieved from <https://igraph.org>
- DeBruine, L. M. (2002). Facial resemblance enhances trust. *Proceedings of the Royal Society B: Biological Sciences*. <https://doi.org/10.1098/rspb.2002.2034>
- De Dominicis, S., Schultz, P. W., & Bonaiuto, M. (2017). Protecting the environment for self-interested reasons: Altruism is not the only pathway to sustainability. *Frontiers in Psychology*, 8, 1–13. <https://doi.org/10.3389/fpsyg.2017.01065>
- DEFRA. (2009). *Survey of public attitudes and behaviours towards the environment*. Retrieved from <https://data.gov.uk/dataset/ab16e19f-a4e1-42e4-9f6e-5ffe2dc7680/survey-of-public-attitudes-and-behaviours-towards-the-environment>

- De Haas, B., Iakovidis, A. L., Schwarzkopf, D. S., & Gegenfurtner, K. R. (2019). Individual differences in visual salience vary along semantic dimensions. *Proceedings of the National Academy of Sciences of the United States of America*, 116(24), 11687–11692. <https://doi.org/10.1073/pnas.1820553116>
- 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>
- Dipple, A., Raymond, K., & Docherty, M. (2014). General theory of stigmergy: Modelling stigma semantics. *Cognitive Systems Research*, 31-32, 61–92. <https://doi.org/10.1016/j.cogsys.2014.02.002>
- Dwyer, P. C., Maki, A., & Rothman, A. J. (2015). Promoting energy conservation behavior in public settings: The influence of social norms and personal responsibility. *Journal of Environmental Psychology*. <https://doi.org/10.1016/j.jenvp.2014.11.002>
- Epskamp, S., Borsboom, D., & Fried, E. (2017). Estimating Psychological Networks and their Accuracy: A Tutorial Paper. *Behavior Research Methods*. Retrieved from <https://arxiv.org/abs/1604.08462>
- Epskamp, S., Borsboom, D., & Fried, E. I. (2018). Estimating psychological networks and their accuracy: A tutorial paper. *Behavior Research Methods*, 50(1), 195–212. <https://doi.org/10.3758/s13428-017-0862-1>
- Epskamp, S., Cramer, A. O., Waldorp, L. J., Schmittmann, V. D., & Borsboom, D. (2012). qgraph: Network visualizations of relationships in psychometric data. *Journal of Statistical Software*, 48(4), 1–18. <https://doi.org/10.18637/jss.v048.i04>
- Fat Knowledge (Blog). (2007). *How Much Energy Does an Elevator Use?* Retrieved from <http://fatknowledge.blogspot.co.uk/2007/02/how-much-energy-does-elevator-use.html>

- Foygel, R., & Drton, M. (2010). Extended Bayesian information criteria for Gaussian graphical models. *Advances in Neural Information Processing Systems*, 23, 2020–2028.
- Frick, J., Kaiser, F. G., & Wilson, M. (2004). Environmental knowledge and conservation behavior: Exploring prevalence and structure in a representative sample. *Personality and Individual Differences*, 37(8), 1597–1613. <https://doi.org/10.1016/j.paid.2004.02.015>
- Griskevicius, V., Tybur, J. M., & Van den Bergh, B. (2010). Going Green to Be Seen: Status, Reputation, and Conspicuous Conservation. *Journal of Personality and Social Psychology*, 98(3), 392–404. <https://doi.org/10.1037/a0017346>
- Hardin, G. (1968). The Tragedy of the Commons. *Science, New Series*, 162(3859), 1243–1248.
- Hines, J. M., Hungerford, H. R., & Tomera, A. N. (1987). Analysis and synthesis of research on responsible environmental behavior: A meta-analysis. *Journal of Environmental Education*, 18(2), 1–8. <https://doi.org/10.1080/00958964.1987.9943482>
- Huebner, G., Shipworth, D., Hamilton, I., Chalabi, Z., & Oreszczyn, T. (2016). Understanding electricity consumption: A comparative contribution of building factors, socio-demographics, appliances, behaviours and attitudes. *Applied Energy*, 177, 692–702. <https://doi.org/10.1016/j.apenergy.2016.04.075>
- Jacob, C., Guéguen, N., & Boulbry, G. (2018). How proof of previous donations influences compliance with a donation request: three field experiments. *International Review on Public and Nonprofit Marketing*, 15, 1–8. <https://doi.org/10.1007/s12208-017-0187-x>
- Kaiser, F. G. (1998). A General Measure of Ecological Behavior. *Journal of Applied Social Psychology*, 28(5), 395–422. <https://doi.org/10.1111/j.1559-1816.1998.tb01712.x>

- Keizer, K., Lindenberg, S., & Steg, L. (2013). The Importance of Demonstratively Restoring Order. *PLoS ONE*, 8(6), 6–12.
<https://doi.org/10.1371/journal.pone.0065137>
- Kollmuss, A., & Agyeman, J. (2002). Mind the Gap: Why Do People Behave Environmentally and What are the Barriers to Pro-Environmental Behaviour. *Environmental Education Research*, 8(3), 239–260.
<https://doi.org/10.1080/1350462022014540>
- Kormos, C., & Gifford, R. (2014). The validity of self-report measures of proenvironmental behavior: A meta-analytic review. *Journal of Environmental Psychology*, 40, 359–371. <https://doi.org/10.1016/j.jenvp.2014.09.003>
- Kubo, T., Shoji, Y., Tsuge, T., & Kuriyama, K. (2018). Voluntary Contributions to Hiking Trail Maintenance: Evidence From a Field Experiment in a National Park, Japan. *Ecological Economics*, 144 (November 2016), 124–128.
<https://doi.org/10.1016/j.ecolecon.2017.07.032>
- Lavelle, M. J., Rau, H., & Fahy, F. (2015). Different shades of green? Unpacking habitual and occasional pro-environmental behavior. *Global Environmental Change*, 35, 368–378. <https://doi.org/10.1016/j.gloenvcha.2015.09.021>
- Leiserowitz, A., Maibach, E., Rosenthal, S., Kotcher, J., Bergquist, P., Gustafson, A., . . . Goldberg, M. (2019). *Politics & Global Warming, November 2019*. Yale University; George Mason University. New Haven, CT: Yale Program on Climate Change Communication. Retrieved from Yale Program on Climate Change Communication website: <https://climatecommunication.yale.edu/wp-content/uploads/2020/01/politics-global-warming-november-2019b.pdf>
- Li, D., Zhao, L., Ma, S., Shao, S., & Zhang, L. (2019). What influences an individual's pro-environmental behavior? A literature review. *Resources, Conservation and Recycling*, 146 (May), 28–34. <https://doi.org/10.1016/j.resconrec.2019.03.024>

- Liobikiene, G., & Poškus, M. S. (2019). The importance of environmental knowledge for private and public sphere pro-environmental behavior: Modifying the Value-Belief-Norm theory. *Sustainability (Switzerland)*, 11(12).
<https://doi.org/10.3390/su10023324>
- MacKay, D. J. C. (2008). *Sustainable Energy — without the hot air* (Vol. 78, p. 383). Cambridge, UK: UIT Cambridge. <https://doi.org/10.1109/PES.2004.1373296>.
- Malle, B. (2011). Attribution theories: How people make sense of behavior. In D. Chadee (Ed.), *Theories in social psychology* (pp. 72–95). Wiley Blackwell.
- Marsh, L., & Onof, C. (2008). Stigmergic epistemology, stigmergic cognition. *Cognitive Systems Research*, 9(1-2), 136–149. <https://doi.org/10.1016/j.cogsys.2007.06.009>
- Martin, R., & Randal, J. (2008). How is donation behaviour affected by the donations of others? *Journal of Economic Behavior and Organization*, 67(1), 228–238.
<https://doi.org/10.1016/j.jebo.2007.08.001>
- Masson-Delmotte, V., Zhai, P., Pörtner, H.-O., Roberts, D., Skea, J., Shukla, P. R., ... Waterfield, T. (2018). *Global warming of 1.5°C. An IPCC Special Report*.
<https://doi.org/10.1017/CBO9781107415324>
- McDonald, R., & Lohse, J. (n.d.). *Avoiding out-group information: information acquisition and group identity (In prep.)*.
- Meyer, A. (2015). Does education increase pro-environmental behavior? Evidence from Europe. *Ecological Economics*. <https://doi.org/10.1016/j.ecolecon.2015.04.018>
- Nash, N., Whitmarsh, L., Capstick, S., Hargreaves, T., Poortinga, W., Thomas, G., ... Xenias, D. (2017). Climate-relevant behavioral spillover and the potential contribution of social practice theory. *Wiley Interdisciplinary Reviews: Climate Change*, 8(6). <https://doi.org/10.1002/wcc.481>
- Newell, B. R., & Shanks, D. R. (2014). Unconscious influences on decision making: A

critical review. *Behavioral and Brain Sciences*, 38(01), 1–19.

<https://doi.org/10.1017/S0140525X12003214>

Nigbur, D., Lyons, E., & Uzzell, D. (2010). Attitudes, norms, identity and environmental behaviour: Using an expanded theory of planned behaviour to predict participation in a kerbside recycling programme. *British Journal of Social Psychology*, 49(2), 259–284. <https://doi.org/10.1348/014466609X449395>

Oceja, L., & Berenguer, J. (2009). Putting text in context: The conflict between pro-ecological messages and anti-ecological descriptive norms. *Spanish Journal of Psychology*, 12(2), 657–666. <https://doi.org/10.1017/S113874160000202X>

Parunak, H. V. D. (2005). A Survey of Environments and Mechanisms for Human-Human Stigmergy. In D. Weyns, H. Van Dyke Parunak, & F. Michael (Eds.), *Lecture notes in computer science* (pp. 163–186). https://doi.org/10.1007/978-3-642-29066-4%7B_%7D11

Poortinga, W., Fisher, S., Boehm, G., Steg, L., Whitmarsh, L., & Ogunbode, C. (2018). *European Attitudes to Climate Change and Energy. Topline Results from Round 8 of the European Social Survey* (p. 20). London: European Social Survey. Retrieved from European Social Survey website: http://www.europeansocialsurvey.org/docs/findings/ESS8%7B/_%7Dtoplines%7B/_%7Dissue%7B/_%7D9%7B/_%7Dclimatechange.pdf

Reingen, P. H. (1982). Test of a list procedure for inducing compliance with a request to donate money. *Journal of Applied Psychology*, 67(1), 110–118. <https://doi.org/10.1037/0021-9010.67.1.110>

Smith, M., Böhnke, J., Graham, H., White, P., & Prady, S. (2016). Associations between active travel and diet: An exploration of pro-health, low carbon behaviours in the national diet and nutrition survey. *J Epidemiol Community Health*, 70(Suppl 1), A18.

Standford Univsersity. (n.d.). *Frequently Asked Questions: Benefits of Recycling*. Retrieved

from <https://lbre.stanford.edu/pssistanford-recycling/frequently-asked-questions/frequently-asked-questions-benefits-recycling>

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>

The British Psychological Society. (2011). *Going Green: The Psychology of Sustainability in the Workplace* (p. 92; D. Bartlett, Ed.).

Thøgersen, J. (2012). *Pro-Environmental Spillover Review of Research on the Different Pathways Through Which Performing One Pro-Environmental Behaviour Can Influence the Likelihood of Performing Another*. (September 2012). Retrieved from <http://www.behaviourworksaustralia.org/V2/wp-content/uploads/2015/10/Review-of-spillover-researchJohn-Th%7B/o%7Dgersen.pdf>

Topf, S., & Speekenbrink, M. (2021). Agent, Behaviour, Trace, Repeat: A Review of the Cognitive Processes Involved in Human Stigmergic Coordination. *PsyArXiv*. <https://doi.org/10.31234/osf.io/pfkyv>

University of Wisconsin-Madison. (n.d.). *Managing Food Waste for Sustainability: Landfills versus Composting*. Retrieved from <https://kb.wisc.edu/dairynutrient/375fsc/page.php?id=48783>

Weideli, D. (2013). *Environmental Analysis of US Online Shopping* (Master thesis). Ecole Polytechnique Fédérale de Lausanne, Switzerland.

Whitmarsh, L. (2009). 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., Capstick, S., Nash, N., & Whitmarsh, L. (2017). Who is reducing their material consumption and why? A cross-cultural analysis of dematerialization behaviours. *Philosophical Transactions of the Royal Society A: Mathematical, Physical and Engineering Sciences*, 375(2095).

<https://doi.org/10.1098/rsta.2016.0376>

Whitmarsh, L., & O'Neill, S. (2010). Green identity, green living? The role of pro-environmental self-identity in determining consistency across diverse pro-environmental behaviours. *Journal of Environmental Psychology*, 30(3), 305–314. <https://doi.org/10.1016/j.jenvp.2010.01.003>

Wikipedia. (n.d.). *Food miles*. Retrieved from https://en.wikipedia.org/wiki/Food_miles

WRAP. (2017). *Estimates of Food Surplus and Waste Arisings in the UK*. Retrieved from http://www.wrap.org.uk/sites/files/wrap/Estimates_of_Food_Surplus_and_Waste_Arisings_in_the_UK.pdf

Supplementary Materials - Instructions

Instructions for Survey 1

In the following, we will show you a number of behaviours. Some of them are pro-environmental behaviours (i.e., they help protect the environment or conserve energy), others will be related behaviours.

For each behaviour, we would like you to list traces for this behaviour. A behavioural trace is any physical evidence or artefact of that behaviour, but not the behaviour itself. Note that traces are generally objects but also include noises, smells and digital evidence (e.g., websites). For example, when you think of cycling, behavioural traces could be

- a bike chained to a rail outside your home or workplace
- bike sheds
- a marked-up cycling lane
- bikes and related accessories (e.g., helmets) sold in shops
- advertisements for cycling schemes at work or in the media
- . . .

Please generate as many behavioural traces as you can think of. You may find it easier to list traces for some behaviours and harder for others. It is entirely up to you in which order you answer and how much time and effort you would like to spend on this. It is fine to leave text fields empty if you cannot think of any traces.

Instructions for Survey 3

Part 1. In the following, you will be given evidence of other people's behaviour.

For each piece of evidence, **we would like you to list possible behaviours that could have caused this piece of evidence.**

For example: **Evidence** = A bike chained to a railing outside the workplace.
Possible causing behaviour 1 = Someone cycled to work. **Possible causing behaviour 2** = Someone drove the bike there in a van. **Possible causing behaviour 3** = Someone pushed the bike walking to work.

For each meaningful response, you will get a bonus payment of £0.05.
 That is, the more behaviours you list, the higher your overall payment. Note that only realistic behaviours count (e.g., in the example above, “an alien having beamed the bike there” would not count). Please be as clear and precise as possible. If we cannot make sense of your answer, it will not count towards your bonus payments. Once submitted, you won’t be able to amend your answer later.

Altogether, **you will see five pieces of evidence.**

If you have any questions before you start, please contact the experimenter through prolific.co.

Part 2. In the following, **you will see some of the behaviours you listed earlier.**

For each behaviour, **we would like you to list possible motivations why someone would engage in this behaviour.**

For example: **Behaviour** = Someone cycled to work. **Possible motivation 1** = Cycling is cheaper than other transport options. **Possible motivation 2** = Cycling is healthier than other transport options. **Possible motivation 3** = The person cycling is training for a triathlon and this is part of their practice.

943 **Again, for each meaningful response, you will get a bonus payment of**
944 **£0.05.** That is, the more motivations you list, the higher your overall payment. Note that
945 only realistic motivations count (e.g., in the example above, “Cycling makes the clouds go
946 pink” would not count). Please be as clear and precise as possible. If we cannot make sense
947 of your answer, it will not count towards your bonus payments. Once submitted, you won’t
948 be able to amend your answer later.

949 **You will see up to five behaviours (fewer if you did not list behaviours in**
950 **the first part of the study).** If you did not name any behaviours, the next page
951 will be empty. It is fine to list similar or the same motivations for different
952 behaviours if that is meaningful.

953 If you have any questions before you start, please contact the experimenter through
954 prolific.co.

Supplementary Materials - Frequencies

Frequency of behaviours

Table 3

Mean and SD for frequency of behaviours engaged in.

Behaviour	Behaviour Short	M	SD
Eat a hot meal (R)	HotMeal	4.2	4.17
Recycle items that can be recycled (e.g., glass, paper, plastic, aluminium)	Recycle	4.1	4.11
Try not to waste food (e.g. by using leftovers)	FoodWaste	4	3.99
Use a large electronic appliance (e.g., a printer, a PC, a TV) (R)	LargeAppliance	4	4.02
Eat a meal that includes meat (R)	Meat	3.7	3.69
Walk for shopping and other errands	WalkShop	3.6	3.63
Shop or order things online	ShopOnline	3.6	3.61
Boil only the amount of water you need (e.g., when using a kettle or cooking)	BoilWater	3.4	3.39
Walk to school, university or work	WalkWork	3.3	3.26
Turn off the TV and other appliances completely (i.e., do not keep them in standby mode)	ApplianceOff	3.2	3.19
Buy a new item (e.g., clothes, luxury items) (R)	NewItems	3.2	3.16
Educate yourself about topics related to sustainability and climate change	Learn	3.1	3.13
Repair a broken item (e.g. computer, phone, household appliance)	Repair	3.1	3.11

Behaviour	Behaviour Short	M	SD
Take a plane for holidays and leisure trips (not counting flying for work) (R)	Fly	3.1	3.07
Take public transport to get to school, university or work	PubTransWork	3.1	3.15
Take public transport for shopping and other errands	PubTransShop	3.1	3.11
Use disposable products (e.g., paper, plastic or styrofoam mugs and food containers) (R)	SingleUseProd	3.1	3.15
Takes steps to reduce water use	WaterUse	3.1	3.08
Use conventional light bulbs (R)	CoventionalLights	3	3.01
Buy an environmentally friendly product (e.g. “green” cleaning products, organic cotton)	GreenProducts	3	2.97
Wash clothes at 30 degrees or lower	Clothes30Degr	3	2.99
Leave the heating on in a room you’re not using (R)	HeatingOn	2.9	2.93
Eat locally grown, in-season food	LocalSeasonFood	2.9	2.86
Eat organic food	OrganicFood	2.8	2.81
Buy items with less packaging or shop zero waste	LessPackaging	2.8	2.77
Buy or use virgin (i.e., non-recycled) paper products (R)	VirginPaper	2.8	2.77
Eat a meat-free (vegetarian) meal	Vegetarian	2.7	2.75
Use single-use plastic shopping bag (R)	SingleUseBag	2.7	2.66

Behaviour	Behaviour Short	M	SD
Leave the lights on in a room you're not using (R)	LightsOn	2.5	2.49
Drive for shopping and other errands (R)	DriveShop	2.5	2.53
Turn on air-conditioning (R)	AirCondition	2.3	2.25
Replace a traditional appliance with an energy efficient appliance (e.g., fridge, printer, washing machine)	EffAppliance	2.3	2.29
Compost food and kitchen waste	Compost	2.3	2.29
Get energy from a renewable or "green" supplier	RenewEnergy	2.2	2.24
Eat a meat-free, egg-free and dairy-free (vegan) meal	Vegan	2.1	2.1
Drive to get to school, university or work (R)	DriveWork	2.1	2.13
Do something together with others to address an environmental issue (e.g., set up recycling scheme)	EnviroScheme	2	1.95
Avoid information about topics related to sustainability and climate change (R)	AvoidInfo	1.9	1.89
Install additional insulation in your home	Insulation	1.9	1.89
Live in, build or buy an energy-efficient home (e.g. passive house)	EffHome	1.9	1.87
Complain about or resist an environmental scheme (e.g., at school or the workplace) (R)	Complain	1.8	1.79
Donate or invest money in a pro-environmental project	Donate	1.8	1.79

Behaviour	Behaviour Short	M	SD
Install a more efficient heating system	HeatingSystem	1.8	1.8
Take part in a campaign or protest about an environmental issue	Campaign	1.7	1.7
Cycle for shopping and other errands	CycleShop	1.7	1.66
Cycle to school, university or work	CycleWork	1.6	1.61
Discourage other people from being more pro-environmental (R)	Discourage	1.4	1.37
Drive an electric car	ElectricCar	1.2	1.18

957 **Frequency of traces**

Table 4

Mean and SD for frequency of traces encountered.

Trace	Trace Short	M	SD
A car parked outside school, university, work or shops (R)	CarParked	6.2	6.22
A sign for public transport (e.g., for tube entrance, train station, bus stops)	PubTransSign	6	5.98
A re-usable item such as a mug/cup, water bottle, lunch container, fabric bag	ReusableItem	5.9	5.85
Bicycle racks outside school, university, work or shops	BikeRack	5.8	5.84
A bicycle parked outside school, university, work or shops	BikeParked	5.8	5.79
A dedicated cycling lane	CyclingLane	5.5	5.45

Trace	Trace Short	M	SD
Someone having or carrying a reusable shopping bag (e.g., in purse, at home or in car boot)	ReusableBag	5.5	5.47
Someone at school, university or work wear waterproof or weather appropriate clothing	Weatherproof	5.3	5.31
Someone having car keys (e.g., on their key ring) (R)	CarKeys	5.3	5.26
A disposable or single-use item such as a paper mug or a plastic take-out container (R)	DisposableItem	5.3	5.3
Water still left in a shared kettle after use (R)	WaterInKettle	5.2	5.22
Someone having or carrying a single use shopping bag (R)	DisposableBag	5.2	5.21
A “suitable for vegetarians” label on a product	SuitVeg	5.1	5.05
The car brand or logo of a petrol or diesel car (R)	PetrolCarLogo	5.1	5.09
Someone having cycling gear (e.g., helmet, clothing, lights, and other accessories)	CyclingGear	5.1	5.1
A delivery van outside someone’s home	DeliveryVan	5.1	5.09
Packaging in bins (e.g. at school, university or work; or at the curb on council collection days) (R)	Packaging	5.1	5.05

Trace	Trace Short	M	SD
Food leftovers in a container (e.g., in a shared fridge at work)	FoodLeftovers	5.1	5.08
That the lights were on when you entered an empty room (R)	Lights	5	5.02
Someone having the newest appliance on the market (e.g., computer, phone) (R)	NewDevice	5	5.02
A “suitable for vegans” label on a food product	SuitVegan	4.8	4.79
Dedicated recycling bins in someone’s home	PrivateRecycling	4.8	4.84
An “organic product” label on food	OrganicLabel	4.7	4.72
Food stored in re-usable containers or re-usable containers ready for shopping	ReusableContainer	4.7	4.69
Holiday photos (e.g., on social media), souvenirs, or postcards from a flight destination (R)	FlightPhotos	4.6	4.59
A parking ticket machine or pay-online instructions (R)	ParkMachine	4.6	4.63
Packaging such as cardboard boxes or bubble wrap from an online delivery	PackagingDelivery	4.6	4.62
Social media posts about or likes of articles about sustainability and climate change	SocMediaArticle	4.5	4.52
An automatically stopping water tap	AutomaticTap	4.5	4.46
An environmentally friendly or “green” product (e.g., reusable items, solar chargers, organic food, green cleaning products)	GreenProduct	4.5	4.46

Trace	Trace Short	M	SD
Holiday photos (e.g., on social media), souvenirs, or postcards from a nearby destination	ClosePhotos	4.5	4.46
A stamp or logo on the paper product stating it is made from recycled material	RecycledPaper	4.5	4.51
An appliance that is unplugged when not in use (e.g. stand-by light is off, room is quiet)	ApplianceOff	4.4	4.42
An eco-label on a product	EcoLabel	4.4	4.36
A recycling bin being set out on council collection days	RecycCollect	4.4	4.38
Social media posts about or likes of a pro-environmental project or campaign	SocMediaCampaign	4.3	4.29
The region label “UK” on a product	Uklabel	4.3	4.28
That someone’s appliance (e.g., computer, phone) look well-used or outdated	UsedDevice	4.3	4.34
A small or fuel-efficient car (e.g., from the brand or make)	FuelEffCar	4.3	4.25
A single-use shopping bag in the bin (R)	DisposableBagBin	4.3	4.32
Pro-environmental messages (e.g., on posters, stickers, t-shirts or tote bags)	PosterSticker	4.2	4.16
That a radiator is switched on when no one is using the room (R)	Heating	4.2	4.25
A bicycle rental or share scheme (e.g., the bicycles themselves)	BikeRental	4.2	4.22

Trace	Trace Short	M	SD
A conventional light bulb visible in the fitting (R)	ConvLightbulb	4.1	4.07
Empty boxes of new items such as shoes or electrical gadgets (R)	NewBox	4.1	4.15
A poster specifying recyclable items	PosterRecycling	4.1	4.14
Lights on a timer switch or with a motion sensor	AutomaticLights	4	4.01
The car brand or logo of an electric vehicle	EcarLogo	4	3.96
A compost or food waste bin available in public (e.g., at school, university or work)	PublicCompost	4	3.96
An air-conditioning unit and/or controls for the unit in the room (R)	AirConUnit	3.9	3.89
Books, magazines, leaflets or documentaries about sustainability or climate change	Books	3.8	3.82
A large suitcase on a train	SuitcaseTrain	3.8	3.79
Someone driving with their windows closed on a hot day (R)	CarWindowClosed	3.7	3.67
Double or treble glazed windows in someone else's home	DoubleGlazedW	3.7	3.67
An energy-efficient light bulb visible in the fitting	EffLightbulb	3.7	3.72
A public charging points for electric vehicles	PublicEcarCharger	3.7	3.69
The noise of an air-conditioning unit (R)	AirConNoise	3.5	3.52
A solar panel on someone's house	SolarPanel	3.5	3.5

Trace	Trace Short	M	SD
A high energy-efficiency rating sticker indicating low energy use on an appliance (e.g., fridge, washing machine)	EffRating	3.5	3.48
Packaging (e.g. boxes) of large appliances after delivery (e.g. fridge, washing machine)	PackagingAppliance	3.5	3.46
A scheme to avoid food waste	FoodWasteScheme	3.5	3.51
An almost-as-new item in second-hand shops (R)	New2ndHand	3.4	3.36
A solar heating panel on someone's house	SolarHeating	3.3	3.33
Comments criticising pro-environmental behaviour (e.g. on social media) (R)	CriticalComments	3.2	3.18
An almost-as-new item in waste bins (R)	NewItemBin	3.2	3.23
A car loaded with holiday gear (e.g., bicycles, canoes, skis)	CarHoliday	3.2	3.21
A caravan or motor home	Caravan	3.2	3.18
Signatures already on a petition list for a pro-environmental issue (online or on paper)	PetitionSign	3.1	3.06
Single-glazed windows in someone else's home (R)	SingleGlazedW	3.1	3.13
Someone wearing mended clothes	MendedClothes	3.1	3.08
A private charging point for electric vehicles	PrivateEcarCharger	3.1	3.12
A compost caddy or replacement bags in someone else's kitchen	KitchenCompost	3.1	3.12
Someone's luggage tagged with a flight number (R)	FlightTag	3	3.02

Trace	Trace Short	M	SD
News, books or magazines that doubt climate change	NewsDoubt	2.9	2.91
Donations to pro-environmental projects or organisations on a crowdfunding website	Donations	2.9	2.92
A warm floor from radiant floor heating	RadiantFloor	2.9	2.93
A compost bin in someone else's garden	PrivateCompost	2.9	2.9
A high energy-efficiency rating on real estate information	HighEffRating	2.8	2.81
A low energy-efficiency rating on real estate information (R)	LowEffRating	2.8	2.75
A large appliance (e.g. fridge, washing machines) being collected for disposal	DisposedAppliance	2.8	2.78
A disposed of appliance (e.g., computer, phone etc.) in the tip or ready for council collection (R)	DeviceDisposed	2.8	2.82
Building works to retrofit insulation (e.g., insulation material on a building site)	InsulationFit	2.7	2.75
Books and magazines about energy efficient building	BuildBook	2.7	2.67
A wind farm (a large number of wind turbines in one place)	WindFarm	2.7	2.75
A rain water collection system in place (e.g., a water butt)	RainCollection	2.6	2.56
A solar farm (a large number of solar panels in one place)	SolarFarm	2.5	2.48

Trace	Trace Short	M	SD
A new pedestrian crossing	PedestrianCrossing	2.4	2.35
Torn-up flyers about a pro-environmental campaign (R)	TornFlyer	2.3	2.27
A coal power station (e.g. a cooling tower) (R)	CoalPowerStation	2.2	2.23
That a petrol station closed down	PetrolClosing	2.1	2.09
A new petrol station opening (R)	PetrolOpening	2	2.04

Supplementary Materials - Impact

Impact of behaviours

We also assessed the impact of each PEB based primarily on MacKay (2008) and where necessary other sources (Anglian Water, n.d.; Automobile Association, n.d.; BBC, 2011; BIO Intelligence Service, 2011; Civil Aviation Authority, 2016; Fat Knowledge (Blog), 2007; Stanford University, n.d.; University of Wisconsin-Madison, n.d.; Weideli, 2013; Wikipedia, n.d.; WRAP, 2017). Comparisons of impacts are difficult because PEBs vary widely in type of energy needed and typical frequency. In line with MacKay (2008), we transformed all energy use to kWh and calculated *typical UK consumer use per day*. For instance, the average UK citizen takes 0.3 domestic, 0.6 EU flights and 0.3 intercontinental flights per year. To calculate the impact of these flights of the average user per day, their kWhs are summed and divided by 365 days. Note that a limitation is that the lifecycle of a product was generally not considered for simplicity. For example, to determine the environmental impact of trading a petrol for an electric car, we should ideally also consider the energy used to produce all materials involved to make the new car. However, this is practically impossible. The impact of some behaviours (e.g., “Avoid littering”) was not determined because although they may have an environmental impact in terms of wildlife, they do not use energy. Once a snack wrapper has been produced, it does not use more energy whether it sits in a landfill or in a ditch. The impact of other PEBs was not determined because they were too vague (e.g. “Vote”, “Campaign”, “Petition”), even though they have a potentially much higher impact than individual behaviours could have *if* they lead to policy changes. Other items such as “Alternative to travelling, e.g. by shopping online” may actually increase energy use if this means delivery vans replace someone picking up an item on the way home or if they are travelling via a more sustainable mode.

Prevalence and impact

Figure 11. Behaviours sorted by frequency according to previous studies plotted against potential average energy reduction (impact). Behaviours in blue did not have their impact assessed.

The correlation between impact and frequency as assessed in previous studies is negative and significant, $r(28) = -0.50$, $p < .001$. This relation represents a mismatch between impact and frequency of behaviours: higher impact is associated with lower

987 frequency of the behaviour. For instance, the most impactful behaviour (“Fly less”) is
988 conducted by 2.75 out of 10 people, the second most impactful behaviour (“Own an electric
989 car or van”) by 0.50 people out of 10. *Figure 11* illustrates this relation. Mean frequency of
990 behaviours assessed in Survey 2 also correlated negatively (but not significantly) with
991 impact, $r(27) = -0.33$, $p = .078$.