

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

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**Abstract**

15

16 The current climate crisis requires pro-environmental behaviours (PEBs) to be developed,  
17 engaged in, and spread to other people. Behavioural traces, i.e. evidence of other people's  
18 pro-environmental behaviour left in the shared environment, have shown to influence people  
19 towards being more pro-environmental. However, systematic research into behavioural  
20 traces of PEBs is missing. In a set of three surveys, we investigate which behavioural traces  
21 correspond to a number of pro- and anti-environmental behaviours identified from previous  
22 literature, how frequently these behavioural traces are encountered, their relation with  
23 engagement in behaviours, and whether behaviours can be inferred from traces. All studies  
24 are survey-based with a mix of open-ended questions (Surveys 1 & 3) and rating scales  
25 (Survey 2). We use network analysis to identify partial correlations between behaviours  
26 and traces. A total of 66 traces uniquely attributed to 36 pro- and anti-environmental  
27 behaviours were identified. On average, each trace is observed monthly. Noticing traces  
28 correlated with engaging in related behaviours in 24 instances. Participants report that if  
29 they saw a trace more frequently, they expect they would be more likely to adopt the  
30 behaviour that produced the trace. Finally, participants were generally able to infer the  
31 causing behaviours when only presented the traces. We show that unique behavioural  
32 traces exist for a number of pro- and anti-environmental behaviours. Traces are noticed  
33 and relate to the constituting behaviours based on correlational and self-report evidence.  
34 Because of the wide variation between behaviours and their traces, further research into  
35 specific behaviours is warranted. Use of these findings for interventions are discussed.

36

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

37

Sustainability

38

Word count: 9164

## 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)<sup>1</sup> 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 (measured in kWh/person-kilometre; MacKay, 2008).

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 social dilemma of the *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. But how do people know that others are engaged in PEBs? One potential route is via behavioural traces. A behavioural trace is the evidence of a behaviour left in the shared environment and distinct from direct observation of that behaviour (Topf & Speekenbrink, 2021). Examples of behavioural traces are a bike left outside a building

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

62 that someone used to cycle there, or the recycling box left set out on collection day as a  
63 trace of the separation behaviour of different materials. The concept of behavioural traces  
64 is borrowed from research on social insects, where environment-mediated coordination can  
65 explain the paradox that non-communicating insects can cooperate effortlessly (Theraulaz  
66 & Bonabeau, 1999). Coordination via behavioural traces is ubiquitous in people's everyday  
67 lives (Parunak, 2005). We follow paths that have been trodden by others, either hoping it  
68 will lead somewhere interesting or simply using it because it is easier (Helbing et al., 1997),  
69 we buy items because others have done so as well, manifested as empty shelf space (Gierl &  
70 Huettl, 2010; Roy & Sharma, 2015; Verhallen & Robben, 1994; Worchel et al., 1975), and  
71 we are more likely to leave an item unwashed in the sink if others left theirs as well  
72 (Raihani & Hart, 2010). There are thus good reasons why behavioural traces could be  
73 instrumental for adopting behaviours in humans, as well, and particularly PEBs. A  
74 meta-analysis of 84 field-experiments showed an effect of Cohen's  $d = 0.59$ , 95% CI [0.52,  
75 0.67], for behavioural traces on behaviour (here: "implicit descriptive norms"; Bergquist et  
76 al., 2019). People are less likely to litter in a clean (vs littered) environment (Cialdini et  
77 al., 1990; Keizer et al., 2013), are more likely to turn off lights and computers when they  
78 initially found the room with those switched off (Bator et al., 2014; Bergquist & Nilsson,  
79 2016; Dwyer et al., 2015; Oceja & Berenguer, 2009), donate when others have already  
80 donated (Jacob et al., 2018; Kubo et al., 2018; Martin & Randal, 2008; Reingen, 1982),  
81 and install solar panels where others have installed them nearby or recently (Baranzini et  
82 al., 2017; Bollinger & Gillingham, 2012; Carattini et al., 2019). Importantly, behavioural  
83 traces are distinct from other forms of communication.

84 First, and in contrast to direct communication and observation, behavioural traces  
85 do not rely on social signals, such as similarity. People tend to trust information from  
86 people more if they resemble them (DeBruine, 2002) or belong to the same group (Brewer,  
87 2008), and even avoid useful information from an out-group source (McDonald & Lohse,  
88 n.d.). Since the observation of a behavioural trace is generally divorced from social

89 appearance, one can learn from a wider range of people, meaning that behaviours are more  
90 likely to spread throughout the whole population, rather than only in a small section of  
91 highly similar people (“bubbles” or “echo-chambers”).

92         Second, behavioural traces can also be more trustworthy than direct communication,  
93 especially when created as the mere by-product of a PEB. Unlike “cheap talk” (Farrell &  
94 Rabin, 1996), where someone could promise to engage in a behaviour but never does so, the  
95 traces could not have been created without actually engaging in the behaviour (Dipple et  
96 al., 2014; Marsh & Onof, 2008). This is especially crucial to consider in the case of PEBs,  
97 where free-riders who convince others to be more pro-environmental without doing so  
98 themselves, still enjoy the benefits such as clean water and fresh air. Because it is crucial  
99 that as many people as possible engage in PEBs for it to make a noticeable difference,  
100 trustworthy signals of engagement are more likely to convince others to also join in.

101         Third, agent and observer do not have to be present at the same time for the  
102 observer to be able to make an inference about the behaviour. This means that  
103 behavioural traces are available for a much longer period than their constituting behaviour,  
104 so that even very fleeting behaviours can have an effect long after they took place. Traces  
105 can also be witnessed by many more observers, and thus have the potential to influence  
106 more people than either direct observation or direct communication could. For instance,  
107 the relatively private separation behaviour is made visible to others through the curbside  
108 recycling box; while observing someone arrive by bike depends on being present at the  
109 right place and at the right time, the bike will be visible for many hours.

110         It is important to note that behavioural traces have been referred to under different  
111 names. For instance, Jacob et al. (2018) looked into the effect of supposedly already  
112 donated coins in a jar (as well as clothes in a bag) on donation behaviour (effectively  
113 behavioural traces of previous donation behaviour) and refer to this as a type social proof  
114 (the concept of social proof captures people’s tendency to use information about how

115 others have behaved in order to determine the appropriate behaviour in a given situation,  
116 see Cialdini & Trost, 1998). *Behavioural residue*, meaning “the physical traces of activities  
117 conducted in the environment” (p. 381; Gosling et al., 2002), or *cue* (Gosling et al., 2005),  
118 as well as *behavioural product* (Lange & Dewitte, 2019) have also been used to describe  
119 what we would call behavioural traces. For instance, Gosling et al. (2005) had participants  
120 make judgements about someone’s personality based on the state of their personal living  
121 spaces. This included objects such as books, magazines and clothes (and whether they are  
122 organised/disorganised, homogenous/varied, many/few), and other physical evidence such  
123 as smells and noises, but also more subjective features such as whether the interior is  
124 “Cheerful (vs. gloomy)” and “Stylish (vs. unstylish)” (p. 695). These observations were all  
125 summarised under the term “cues”, although we would only call the physical evidence such  
126 as objects, smells and noises “behavioural traces”. Since “cue” can refer to qualitatively  
127 very different types of information, ranging from the clothes someone wears to nonverbal  
128 behaviour such as smiling or frowning (Kenny et al., 1992), rather than using terms such as  
129 “cue” or “social proof”, we thus use *behavioural traces* when referring to “physical evidence  
130 of behaviour”. Similarly, the areas of social learning, public information use and social  
131 eavesdropping also often include variations of behavioural traces under different names and  
132 without strict delineation from other sources of information, such as direct observation  
133 (Bonnie & Earley, 2007). Another important term is *implicit descriptive norms*, defined as  
134 norms that “communicate the social norms by subtle cues in the environment, indicating  
135 what other people have done or (dis)approve of” (Bergquist et al., 2019, p. 2). Descriptive  
136 social norms, however, generally make reference to what proportion of other people engage  
137 in that behaviour, whereas a few people could have caused the behavioural traces (e.g., one  
138 person could have switched off all the computers in a room), denoting no norm at all but  
139 the preference of a small, dedicated group. Behavioural traces thus *can* be a reflection of  
140 social norms, but do not necessarily have to be. We decided to use the term “behavioural  
141 traces” to refer to physical evidence, independent of whether they stem for a majority or



## 164 **Methods**

### 165 *Identification of pro-environmental behaviours*

166 To identify PEBs, we conducted an extensive literature search<sup>2</sup>. We searched for  
167 studies that (a) were from the UK (because behaviours and their traces may differ by  
168 country), (b) used quantitative measures, (c) looked at more than one behaviour, (d) had a  
169 representative sample, (e) had at least 500 participants, and (f) were conducted within the  
170 last 10 years (2009-2019). The latter restriction was included under the assumption that  
171 prevalence and perceptions of PEBs may have changed rapidly over previous decades  
172 (Ballew et al., 2019). This search delivered 311 results. After sighting abstracts for the  
173 above criteria, 30 studies remained included. Of these, a further 25 were excluded because  
174 they did not report or measure individual PEBs, were based on existing data, or used  
175 unrepresentative samples. The remaining five studies (1 UK, 3 England, 1 Ireland &  
176 Northern Ireland) asked participants to rate how often they engaged in a number of PEBs  
177 (see *Table 1*; Whitmarsh, 2009; Huebner et al., 2016; Lavelle et al., 2015; Whitmarsh et al.,  
178 2017; Whitmarsh & O'Neill, 2010). Additionally, we included items from three waves of the  
179 Energy and Climate Change Public Attitude Tracker, compiled by the UK Department for  
180 Business, Energy and Industrial Strategy (BEIS, 2017), and the UK Survey of Public  
181 Attitudes and Behaviours toward the Environment (SABE; DEFRA, 2009). In summary,  
182 we identified 62 PEBs from previous literature. We added the corresponding  
183 anti-environmental behaviours to this list before presenting the behaviours to participants  
184 in Survey 2.

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<sup>2</sup> Using the search string ((“pro\*environmental behavio\*r\*” OR “sustainable behavio\*r\*” OR “ecological behavio\*r\*” OR “environmental behavio\*r\*” OR “green behavio\*r\*” OR (“behavio\*r\*” AND “climate”)) AND (prevalence OR representative OR public OR household\*) AND (“UK” OR “Northern Ireland” OR “Wales” OR “England” OR “Scotland”)) on Web of Science (<http://webofknowledge.com>), which contains articles from more than 20,000 peer-reviewed journals. Date of search: 20/09/2019.



**Table 1***Studies of PEBs 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 <sup>(a)(b)</sup>
BEIS waves 1-21	44141	12 <sup>(c)</sup>	Always - Very often - Quite often - Occasionally - Never <sup>(b)</sup>

<sup>(a)</sup> Behaviours were answered on different scales; reported are the sum of percentages of the following answers: 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.

<sup>(b)</sup> For some of the items, the possible answers also included 'Don't know' and 'Not applicable'.

<sup>(c)</sup> Not all items were included in all waves.

## 185 *Participants*

186 Thirty-nine participants were recruited as volunteers via word-of-mouth and social  
 187 media ( $N = 21$ ) as well as from the University College London (UCL) psychology subject  
 188 pool ( $N = 18$ ).<sup>3</sup> The latter set of participants were students who received course credit for  
 189 their participation. The survey had approval from the UCL Research Ethics Committee.

<sup>3</sup> Demographics were not collected for this survey to keep it brief.

## 190 *Procedure*

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

## 205 **Results**

206 Each of the 89 pro- and anti-environmental behaviours was presented on average to  
207 11 participants (min = 7, max = 15). Participants generated a total of 442 traces, or on  
208 average 5.26 traces per behaviour (min = 1, max = 13; pro- and anti-environmental  
209 behaviours counted separately).

210 Traces were excluded if they were exact duplicates (27 responses) or very similar to  
211 a trace for a different PEB and thus ambiguous (23) or ambiguous in terms of how many  
212 other behaviours not included in the study could have caused it (e.g., “A blanket draped  
213 over the sofa in someone else’s house” as a trace for the behaviour “Bought or built a  
214 traditional home”; 50). Traces were also excluded if they tended to be too private (e.g., “A  
215 high energy bill”; 68) or otherwise hard to know about (e.g., “Items past sell-by date in a

216 shared fridge / shared pantry”; 59). Traces mediated by a third party in response to  
217 others’ behaviour, such as the selection of options (e.g., “Meat options in restaurants and  
218 cafés”, 37) as well as labels (e.g., “A ‘suitable for vegetarians’ label on a product”, 9) were  
219 also excluded. This is because these “mediated traces” are not direct evidence of  
220 individuals’ behaviour.

221 This procedure reduced the number of unique traces to 66. Behaviours and the  
222 numbers of associated traces generated (plus reasons for exclusions) can be found in the  
223 *Supplementary Materials*. In the final list, 36 of the initial behaviours had at least one  
224 unique trace (23 pro- and 13 anti-environmental behaviours). Most of the final behaviours  
225 were linked to one unique trace (median = 1, min = 1, max = 4). The item with the most  
226 traces was “Takes train or car for holidays or leisure trips instead of flying (this excludes  
227 travelling for work)” (4 traces), followed by “Bought or built an energy-efficient home  
228 (e.g. passive house)”, “Frequently buys new items (e.g., clothes, luxury items)”, “Runs  
229 air-conditioning”, and “Takes part in a campaign or protest about an environmental issue”  
230 (3 traces each).

## 231 Discussion

232 Participants generated on average one behavioural trace for each of the previously  
233 identified PEBs and their related anti-environmental behaviours. Fifty-three behaviours  
234 had no unique, unambiguous trace. These behaviours may leave a trace, but it is difficult  
235 to distinguish it from the traces created by other behaviours. For instance, a trace  
236 identified for the behaviour “Avoids buying new things (e.g., clothes, luxury items)” was  
237 “Others’ shoes and clothes looked worn-out, e.g., threads, pillings, fading colours”. This  
238 trace, however, could have alternative causing behaviours, such as the person being careless  
239 with their belongings. The results suggest that just as some PEBs are more visible than  
240 others (Brick et al., 2017), there are also differences in the visibility of behavioural traces.  
241 Future research could investigate whether there is a link between the visibility of traces

242 and the likelihood of people engaging in the related PEBs, that is whether people decide to  
243 (not) engage in PEBs based on whether their own traces are visible, as has been found for  
244 the visibility of PEBs themselves (Brick et al., 2017; Griskevicius et al., 2010).

## 245 **Survey 2 - Frequency of Behaviours and Behavioural Traces**

246 The main goal of Survey 2 was to understand how frequently the behavioural traces  
247 generated from Survey 1 are observed, and whether there is a relation between observing  
248 traces and conducting PEBs. For the individual, PEBs constitute a social dilemma where  
249 one's contribution is negligible and only many acts of, for instance, energy saving  
250 behaviours, can have a meaningful, global impact. A large proportion of people behave as  
251 conditional cooperators in social dilemmas (Fischbacher et al., 2001), meaning that they  
252 are likely to cooperate on issues that require collective action, provided they know or at  
253 least believe that others cooperate as well (Komorita & Parks, 1996). This conditional  
254 cooperation strategy is evolutionary very stable because it cannot easily be exploited by  
255 uncooperative others, while being very successful when encountering cooperative others  
256 (Axelrod & Hamilton, 1981). Behavioural traces can deliver information on whether others  
257 cooperate, that is, behave pro-environmentally. In this context it is secondary whether  
258 many of these energy saving acts are performed by a small group, or whether a large group  
259 performs some acts. What is important is the overall frequency. Here we thus ask how  
260 often behavioural traces are encountered as a measure of how many times PEBs had been  
261 performed by others. We hypothesise that observing more behavioural traces of a  
262 behaviour makes it more likely that someone engages in the behaviour as well, since this  
263 increases the chances that together these acts amount to meaningful impact.

## 264 **Methods**

### 265 *Participants*

266 Previous studies (Bergquist et al., 2019) had found an effect size of  $d = .59$  from  
267 traces to behaviour. This equates to a correlation coefficient of  $r = .28$  (Ruscio, 2008).

268 Taking a smaller effect of  $r = .20$ , we would need to collect  $N = 259$  participants with a  
269 type I error rate of  $\alpha = 0.05$  and power  $1 - \beta = .90$ . Since we were looking at many  
270 correlations in this cross-sectional design, we increased the sample to the maximum  
271 number founds allowed, while at the same time using statistical procedures that reduced  
272 the possibility of false-positive findings (for details see below).

273 In total, 806 participants completed the online survey (Age  $M = 39.40$ ,  $SD = 17.23$ ,  
274 51.86% female, 75.95% white ethnicity). Participants were recruited as a representative UK  
275 sample via Prolific ([www.prolific.co/](http://www.prolific.co/); Palan & Schitter, 2018) and received payments of  
276 £1.25. A non-representative subset of 162 participants (Age  $M = 19.70$ ,  $SD = 5.72$ ,  
277 55.56% female) also answered open questions and received £2.00. The survey was  
278 approved by the UCL Research Ethics Committee.

## 279 **Materials**

280 *Traces questionnaire.* This questionnaire included 66 traces identified in Survey 1  
281 (*Supplementary Materials, Table 4*). Participants were asked how often they had noticed  
282 the relevant trace in the past three months on a scale from “Never” (1), “Not in the last  
283 three months” (2), “Once or twice” (3), “About monthly” (4), “About weekly” (5),  
284 “Several times a week” (6), to “About daily” (7).

285 *Behaviours questionnaire.* In total, 36 behaviours corresponded to the 66 traces  
286 described in Survey 1 and constituted this questionnaire. Both pro- and anti-environmental  
287 behaviours were represented (*Supplementary Materials, Table 3*). Participants were asked  
288 how often they typically engage in the behaviour, on a scale from “Never” (1), “Rarely”  
289 (2), “Sometimes” (3), “Often” (4), to “Always” (5).

290 *In-/ decrease of behaviour.* A smaller subset of participants were asked two  
291 open-ended questions about when seeing traces made them increase or decrease the  
292 frequency of their behaviour: “Please give specific examples of when seeing traces increased  
293 (decreased) your own behaviour, i.e., because you saw traces, you did something more

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

### 302 ***Procedure***

303 The survey was hosted on Gorilla (www.gorilla.sc; Anwyl-Irvine et al., 2020). After  
304 the aim of the study had been explained, participants were asked for their consent. They  
305 then answered the frequency of behaviours and the frequency of traces questionnaires.  
306 Order of presentation of the two questionnaires was randomised and counterbalanced.  
307 Presentation of items within questionnaires was also randomised. In the last section, a  
308 subset of participants were additionally asked the open-ended and rating questions about  
309 in-/ or decrease of their behaviour. All participants were then thanked and debriefed, after  
310 which they had the chance to leave any comments.

### 311 ***Data analysis***

312 A Gaussian Markov random field model (Epskamp et al., 2018) was used to  
313 estimate a network of the relations between frequency of behaviours and traces. The  
314 network is based on partial polychoric correlations using “least absolute shrinkage and  
315 selection operator” (LASSO) regularisation. This means that the total sum of absolute  
316 parameter values is limited. Therefore, some parameters are forced to zero and  
317 subsequently drop out of the model. The threshold for this is set through the Extended  
318 Bayesian Information Criterion (EBIC) hyperparameter  $\gamma$ . EBIC is typically set between 0  
319 and 0.5, with higher values favouring a more sparse network (Foygel & Drton, 2010). We

320 selected  $\gamma = 0.5$  with the goal of obtaining a simple model and minimising the risk of false  
321 positives. In addition to edges, we report the centrality of behaviours and traces using  
322 “node strength”, which is calculated by summing the absolute edge weights for that node.  
323 This is more reliable than other centrality measures such as betweenness (Epskamp et al.,  
324 2018). Finally, the accuracy of the edges and strengths are estimated using non-parametric  
325 bootstrapping ( $n = 1000$ ) whereby data are resampled with replacement and confidence  
326 intervals of the partial correlations can be calculated (Epskamp et al., 2018). The network  
327 analysis is conducted with R packages *bootnet* (Epskamp et al., 2018) and *qgraph*  
328 (Epskamp et al., 2012), and illustrated using *igraph* (Csardi & Nepusz, 2006).

## 329 Results

### 330 *Frequency of behaviours*

331 Out of the 36 pro- and anti-environmental behaviours presented, the three reported  
332 as most frequently performed were “Recycle items that can be recycled (e.g., glass, paper,  
333 plastic, aluminium)”,  $M = 4.40$ ,  $SD = 4.42$ , “Try not to waste food (e.g. by using  
334 leftovers)”,  $M = 4.30$ ,  $SD = 4.29$ , and “Shop or order things online”,  $M = 3.70$ ,  
335  $SD = 3.70$ <sup>4</sup>; the three least frequently performed behaviours were “Drive an electric car”,  
336  $M = 1.10$ ,  $SD = 1.13$ , “Discourage other people from being more pro-environmental (R)”<sup>5</sup>,  
337  $M = 1.30$ ,  $SD = 1.32$ , and “Cycle to school, university or work”,  $M = 1.50$ ,  $SD = 1.55$ .  
338 All behaviours and mean frequencies are presented in *Supplementary Materials, Table 3*.

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<sup>4</sup> Online shopping was long seen to be more pro-environmental as it was compared to individual (driving) trips for that item. However, the surge of online shopping in combination with quick delivery promises means that online shopping has higher impact than brick-and-mortar shopping, especially when this would be on-route to/from work or by more environmental means, such as public transport, cycling or walking (Weideli, 2013).

<sup>5</sup> “(R)” refers to a reversed, or anti-environmental, item.

### 339 *Frequency of traces*

340 On average, each trace is observed monthly,  $M = 3.90$ ,  $SD = 1$ . The three traces  
341 reported as most frequently observed (i.e., several times a week) were “A car parked  
342 outside school, university, work or shops (R)”,  $M = 6.20$ ,  $SD = 1.30$ , “A delivery van  
343 outside someone’s home”,  $M = 5.90$ ,  $SD = 1.22$ , and “The car brand or logo of a petrol or  
344 diesel car (R)”,  $M = 5.70$ ,  $SD = 1.75$ . The three traces reported as observed least  
345 frequently (i.e., not in the last three months) were “Torn-up flyers about a  
346 pro-environmental campaign (R)”,  $M = 1.90$ ,  $SD = 1.27$ , “Books and magazines about  
347 energy efficient building”,  $M = 2.30$ ,  $SD = 1.40$ , and “A warm floor from radiant floor  
348 heating”,  $M = 2.40$ ,  $SD = 1.49$ . All traces and mean frequencies are presented in  
349 *Supplementary Materials, Table 4*.

### 350 *Co-occurrence of behaviours and traces*

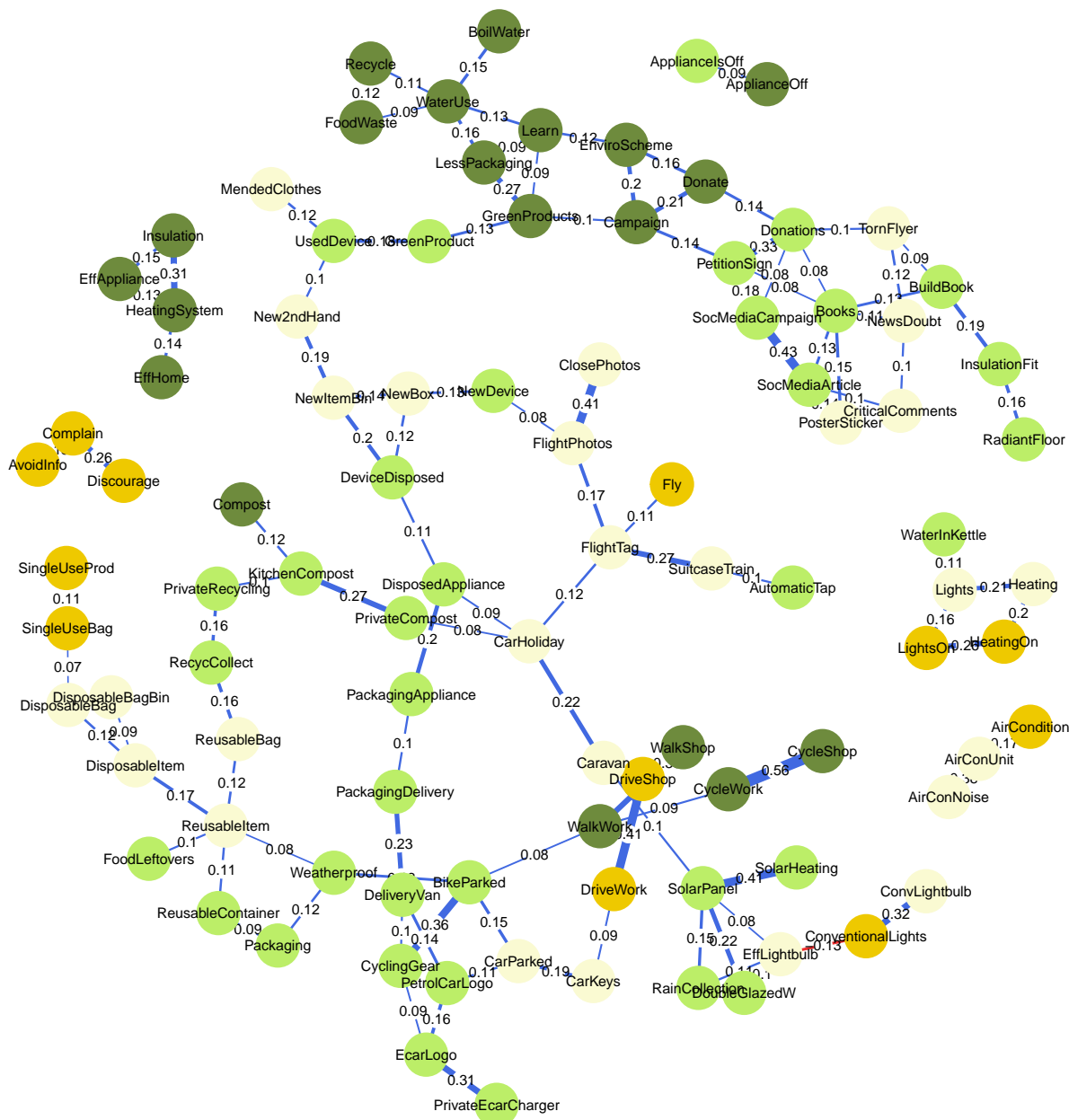
351 A partial correlations network of PEBs and their traces (green nodes) and  
352 anti-environmental behaviours and their traces (yellow nodes) is visualised in *Figure 1*.<sup>6</sup>  
353 The network shows one larger cluster of behaviours around household behaviours (the use  
354 of “green” products, reduced water use and packaging, and recycling correlate) and around  
355 activism behaviours (learn about climate change, campaign, donate and engage in an  
356 environmental scheme). There are some smaller clusters, for instance around transport  
357 (people who cycle or walk are less likely to drive, *et vice versa*) and around improving the  
358 energy efficiency of one’s home (install insulation and a more efficient heating system,  
359 replace an appliance with a more efficient one).

360 Connections between observing traces of others’ behaviours and engaging in  
361 behaviours can also be observed in a number of instances (see *Table 2*). One of the  
362 strongest connections is between noticing the trace “A conventional light bulb visible in the  
363 fitting (R)” and the behaviour “Use conventional light bulbs (R)”,  $r = .32$ , which is

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<sup>6</sup> Exact item wording can be found in the *Supplementary Materials*.





**Figure 1**

*Correlation network of pro-environmental behaviours (light green), anti-environmental behaviours (dark green), pro-environmental traces (light yellow) and anti-environmental traces (dark yellow). Positive partial correlation are depicted as blue edges and negative partial correlations as red edges and only shown if they are significant at  $p < .001$  level. Nodes are placed close to each other when there is a significant correlation, otherwise placement is random.*

364 positive; yet noticing “An energy-efficient light bulb visible in the fitting” correlates  
365 negatively with the same behaviour,  $r = -.13$ . The second strongest connection is between  
366 the trace “That a radiator is switched on when no one is using the room (R)” and the  
367 behaviour “Leave the heating on in a room you’re not using (R)”,  $r = .20$ .

368         In most cases the correlations between traces and behaviours are positive. That is,  
369 in general seeing a pro-environmental trace correlates positively with engaging in a  
370 (related) PEB and negatively with engaging in a (related) anti-environmental behaviour.  
371 The only exceptions to this are that people who likely notice “A large suitcase on a train”  
372 (a pro-environmental trace), are also more likely to “Take a plane for holidays and leisure  
373 trips (not counting flying for work) (R)” (an anti-environmental behaviour), and that  
374 people who likely notice “A caravan or motor home” (a pro-environmental trace), are also  
375 more likely to “Drive for shopping and other errands (R)” (an anti-environmental  
376 behaviour).

**Table 2**  
*Significant partial correlations of behaviours and traces, based on bootstrapped network estimations (Survey 2).*

Trace	Behaviour	r	95% CI	p
A conventional light bulb visible in the fitting (R)	Use conventional light bulbs (R)	.32	[.27,.38]	<.001 ***
That a radiator is switched on when no one is using the room (R)	Leave the heating on in a room you're not using (R)	.20	[.14,.26]	<.001 ***
An air-conditioning unit and/or controls for the unit in the room (R)	Turn on air-conditioning (R)	.17	[.12,.22]	<.001 ***
That the lights were on when you entered an empty room (R)	Leave the lights on in a room you're not using (R)	.16	[.11,.22]	<.001 ***
Signatures already on a petition list for a pro-environmental issue (online or on paper)	Take part in a campaign or protest about an environmental issue	.14	[.09,.19]	<.001 ***
Donations to pro-environmental projects or organisations on a crowdfunding website	Donate or invest money in a pro-environmental project	.14	[.08,.19]	<.001 ***
An environmentally friendly or 'green' product (e.g., reusable items, solar chargers, organic food, green cleaning products)	Buy an environmentally friendly product (e.g. 'green' cleaning products, organic cotton)	.13	[.08,.19]	<.001 ***
An energy-efficient light bulb visible in the fitting	Use conventional light bulbs (R)	-.13	[-.19,-.07]	<.001 ***
A compost caddy or replacement bags in someone else's kitchen	Compost food and kitchen waste	.12	[.06,.18]	<.001 ***
A caravan or motor home	Drive for shopping and other errands (R)	.12	[.06,.17]	<.001 ***
Someone's luggage tagged with a flight number (R)	Take a plane for holidays and leisure trips (not counting flying for work) (R)	.11	[.05,.17]	<.001 ***
An appliance that is unplugged when not in use (e.g. stand-by light is off, room is quiet)	Turn off the TV and other appliances completely (i.e., do not keep them in standby mode)	.09	[.02,.16]	<.001 ***
Someone having car keys (e.g., on their key ring) (R)	Drive to get to school, university or work (R)	.09	[.03,.15]	.001 **

**Table 2**  
*Significant partial correlations of behaviours and traces, based on bootstrapped network estimations (Survey 2). (continued)*

Trace	Behaviour	r	95% CI	p
A bicycle parked outside school, university, work or shops	Walk to school, university or work	.08	[.04,.13]	.001 **
Torn-up flyers about a pro-environmental campaign (R)	Complains about 'green' scheme (R)	.08	[.02,.14]	.005 **
A large suitcase on a train	Take a plane for holidays and leisure trips (not counting flying for work) (R)	.08	[.02,.14]	.006 **
A recycling bin being set out on council collection days	Recycle items that can be recycled (e.g., glass, paper, plastic, aluminium)	.07	[.01,.14]	.006 **
Books, magazines, leaflets or documentaries about sustainability or climate change	Educate yourself about topics related to sustainability and climate change	.07	[.02,.13]	.003 **
Someone having or carrying a single use shopping bag (R)	Use single-use plastic shopping bag (R)	.07	[.01,.13]	.001 **
Books and magazines about energy efficient building	Do something together with others to address an environmental issue (e.g., set up recycling scheme)	.07	[.02,.13]	.008 **
Social media posts about or likes of articles about sustainability and climate change	Educate yourself about topics related to sustainability and climate change	.07	[.02,.12]	.004 **
Building works to retrofit insulation (e.g., insulation material on a building site)	Install additional insulation in your home	.07	[.01,.12]	.010 *
A rain water collection system in place (e.g., a water butt)	Compost food and kitchen waste	.06	[.00,.12]	.015 *
The noise of an air-conditioning unit (R)	Turn on air-conditioning (R)	.06	[.00,.11]	.019 *
A solar panel on someone's house	Replace a traditional appliance with an energy efficient appliance (e.g., fridge, printer, washing machine)	.05	[.00,.11]	.022 *

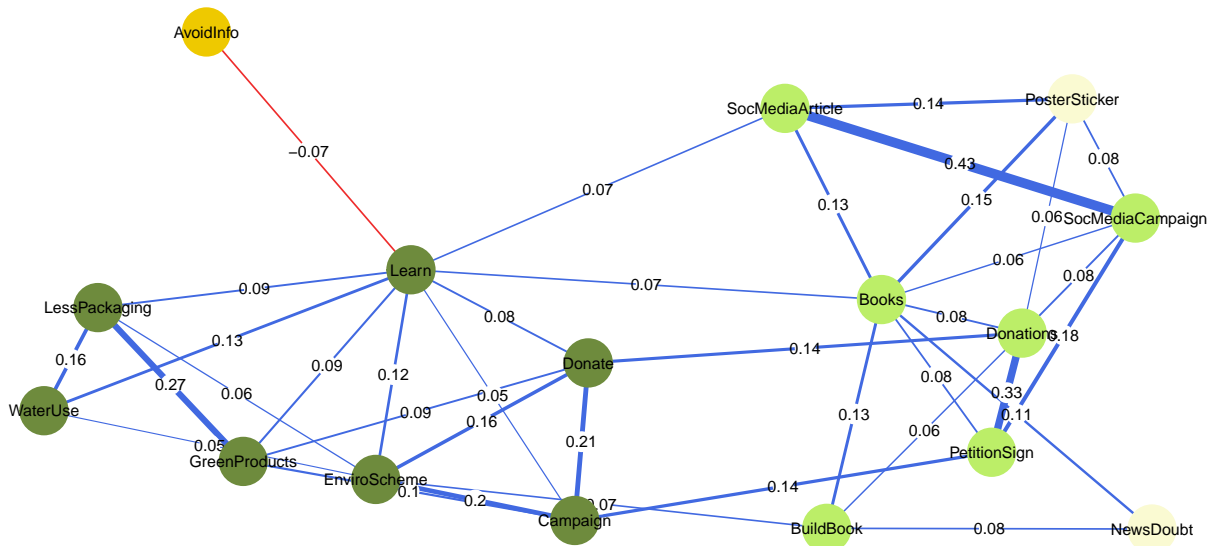
\* p < .05, \*\* p < .01, \*\*\* p < .001

377 The network also shows that links among traces and links among behaviours are  
378 more likely to occur, respectively, than *between* traces and behaviours. *Figure 4* shows *node*  
379 *strength* and their 95% confidence intervals as a measure of centrality for behaviours and  
380 traces. High centrality means that these nodes are well connected with other behaviours  
381 and traces—if a person engages in this behaviour or notices that trace, they are also more  
382 likely to engage in other behaviours and see other traces. For instance, reducing water  
383 usage or taking part in an environmental scheme or using “green” products means that it is  
384 likely this person also takes other pro-environmental actions. Nodes of high centrality  
385 could therefore be leverage points for interventions, in order to increase overall  
386 pro-environmental engagement. Traces are generally more connected than behaviours,  
387 which tend to cluster in small groups instead. Traces could thus be leverage points.

388 For instance, people who see the trace “Social media posts about or likes of articles  
389 about sustainability and climate change”, are more likely to “Educate yourself about topics  
390 related to sustainability and climate change”. Once they do this, they are also more likely  
391 to engage in other, related PEBs, such as “Do something together with others to address  
392 an environmental issue (e.g., set up recycling scheme)”, “Donate or invest money in a  
393 pro-environmental project”, and “Buy an environmentally friendly product (e.g. ‘green’  
394 cleaning products, organic cotton)” (see *Figure 2*).

395 But the reverse also applies: People who rarely see the trace “Water still left in a  
396 shared kettle after use (R)”, are more likely to “Boil only the amount of water you need  
397 (e.g., when using a kettle or cooking)”. Engaging in this specific water-conserving  
398 behaviour, they are also more likely to engage in other, related PEBs, such as general  
399 “Takes steps to reduce water use”, and “Try not to waste food (e.g. by using leftovers)”,  
400 but they are also less likely to “Leave the lights on in a room you’re not using (R)” or  
401 “Leave the heating on in a room you’re not using (R)” (see *Figure 3*).

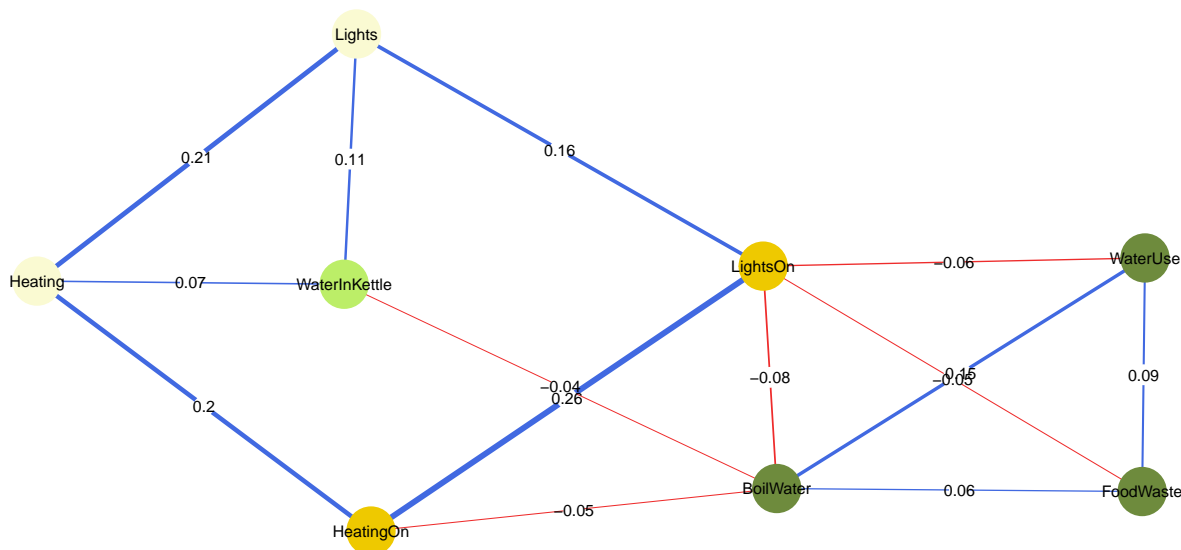
402 The network also shows that links among traces and links among behaviours are



**Figure 2**

Zoom into the partial correlations network for the relation between trace “Social media posts about or likes of articles about sustainability and climate change” (SocMediaArticle) and behaviour “Educate yourself about topics related to sustainability and climate change” (Learn) and their significant first-order connections.

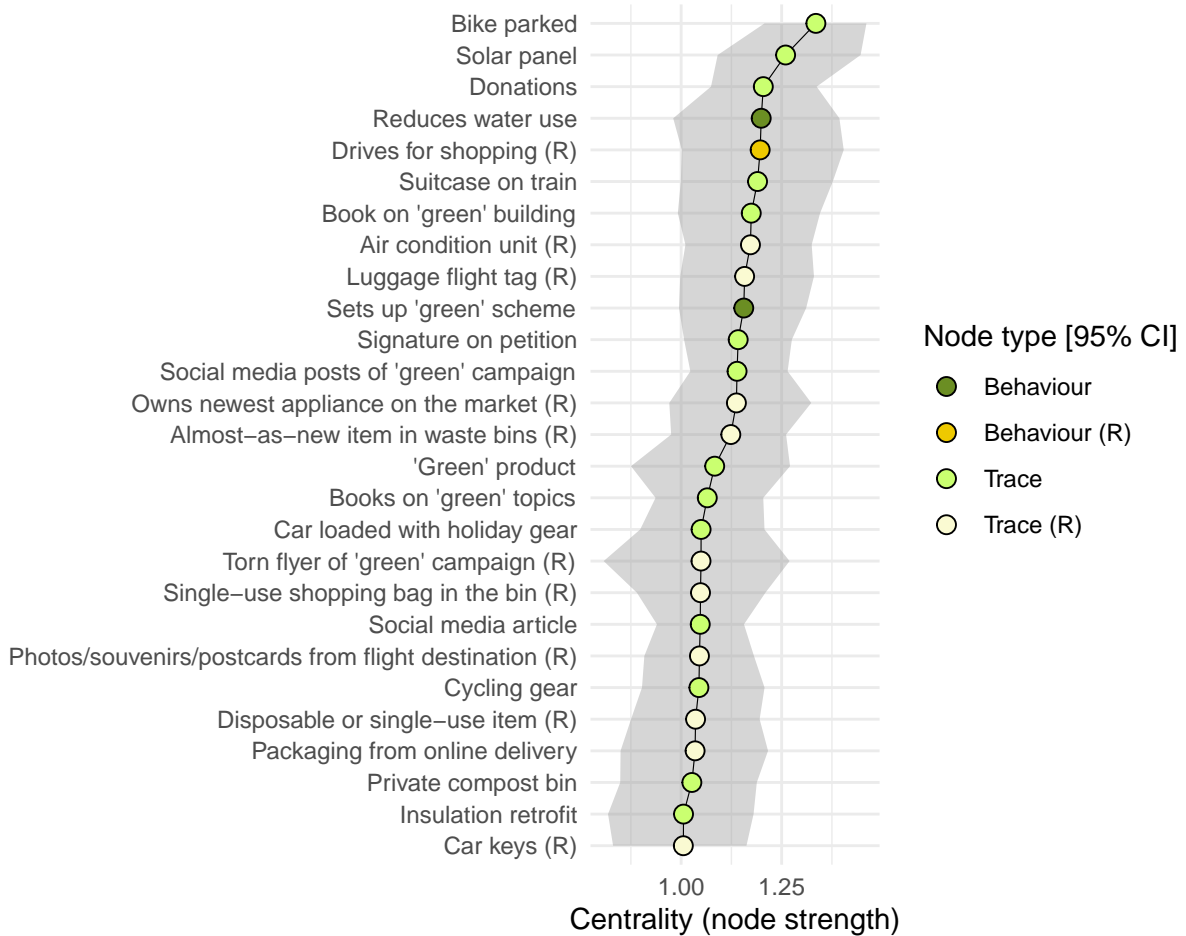
403 more likely to occur, respectively, than *between* traces and behaviours. *Figure 4* shows *node*  
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 405 traces. High centrality means that these nodes are well connected with other behaviours  
 406 and traces—if a person engages in this behaviour or notices that trace, they are also more  
 407 likely to engage in other behaviours and see other traces. For instance, reducing water  
 408 usage or taking part in an environmental scheme or using “green” products means that it is  
 409 likely this person also takes other pro-environmental actions. Nodes of high centrality  
 410 could therefore be leverage points for interventions, in order to increase overall  
 411 pro-environmental engagement. Traces are generally more connected than behaviours  
 412 (*Figure 4*), which tend to cluster in small groups instead. Traces could thus be leverage  
 413 points. For instance, people who see the trace “Social media posts about or likes of articles  
 414 about sustainability and climate change”, are more likely to “Educate yourself about topics



**Figure 3**

Zoom into the partial correlations network for the relation between trace “Water still left in a shared kettle after use (R)” (*WaterInKettle*) and behaviour “Boil only the amount of water you need” (*BoilWater*) and their significant first-order connections.

415 related to sustainability and climate change”. Once they do this, they are also more likely  
 416 to engage in other, related PEBs, such as “Do something together with others to address  
 417 an environmental issue (e.g., set up recycling scheme)”, “Donate or invest money in a  
 418 pro-environmental project”, and “Buy an environmentally friendly product (e.g. ‘green’  
 419 cleaning products, organic cotton)” (see *Figure 3*). But the reverse also applies: People  
 420 who rarely see the trace “Water still left in a shared kettle after use (R)”, are more likely to  
 421 “Boil only the amount of water you need (e.g., when using a kettle or cooking)”. Engaging  
 422 in this general water-conserving behaviour, they are also more likely to engage in other,  
 423 related PEBs, such as general “Takes steps to reduce water use”, and “Try not to waste  
 424 food (e.g. by using leftovers)”, but they are also less likely to “Leave the lights on in a  
 425 room you’re not using (R)” or “Leave the heating on in a room you’re not using (R)” (see  
 426 *Figure 2*).



**Figure 4**

*Pro- (dark green) and anti-environmental (dark yellow) behaviours, as well as pro- (light green) and anti-environmental (light yellow) traces with centrality (node strength or “connectedness”) greater or equal to 1, with 95-percent confidence intervals (grey area).*



### 427 *Subjective impact of behavioural traces*

428 A subset of the 162 participants answered additional questions related to the  
429 subjective impact of behavioural traces. On average, participants reported that if they  
430 never saw a currently frequent trace again, it would likely not affect their behaviour,  
431  $M = 48.20$ ,  $SD = 23.99$ ; on a scale from 0 (less often) to 100 (more often). However, if  
432 they were to see a currently infrequent trace daily in the future, participants reported they  
433 would likely engage in the related behaviour more often,  $M = 59.60$ ,  $SD = 22.81$ .

434 When asked about a specific example of when seeing a trace actually decreased or  
435 increased their behaviour, the most frequently mentioned trace was “(Images of) plastic in  
436 the environment (e.g., oceans)” with 16 mentions. This influenced a number of behaviours,  
437 including “Use reusable shopping bag/Avoid single-use plastic bags” (5 mentions), “Recycle  
438 more” (4), “Use reusable products/Avoid disposable products” (4), “Avoid plastics” (2),  
439 and specifically “Use reusable water bottle” (1). The second most frequent traces were  
440 “Dedicated recycling bins” and “Littering”, both with 14 mentions, respectively. The  
441 former trace led to “Recycle more” (14). The latter trace mainly meant that people “Don’t  
442 litter” (8), “Avoid disposable cups/Avoid plastics/Avoid single-use plastic bags/Use  
443 reusable water bottle” (4) and finally also “Recycle more” (2). Also often reported are the  
444 traces “Lights on” (11) and “Reusable shopping bag” (11).

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

449 In general, a PEB was more likely to *increase* (61.74%) than decrease (38.26%) if  
450 the trace was pro-environmental. But when the trace was anti-environmental, the related  
451 behaviour is more likely to *decrease* (65.71%) than increase (34.29%). This difference  
452 between de-/increase of behaviour and type of trace is significant,  $\chi^2(1) = 12.05$ ,  $p = .001$ ,

453 showing that trace and behaviour are aligned: More pro-environmental traces mean an  
454 increase in pro-environmental behaviours, more anti-environmental traces mean a decrease  
455 in pro-environmental behaviours.

## 456 Discussion

457 Not previously investigated, there is substantial variability in whether behavioural  
458 traces are noticed, ranging between “Daily” to “Never before”. The patterns of relations  
459 between behaviours and traces determined in the network analysis make intuitive sense.  
460 For instance, a cluster emerged around travel habits, where modes of travel correlate  
461 positively if they are both pro- or both anti-environmental but negatively if they are  
462 opposites. Other clusters can be seen around home improvements to be more energy  
463 efficient, and around pro-environmental activism. According to participants’ reports, a  
464 PEB was more likely to *increase* with noticing a pro-environmental trace and more likely  
465 to decrease if the trace was anti-environmental.

466 There are three interesting results to highlight from Survey 2. Firstly, there were  
467 correlations among behaviours that tend to be relatively easy, such as recycling, reduced  
468 water usage, or boiling only as much water as needed, and correlations among more  
469 difficult or “committed” behaviours (such as substantial changes to one’s home), but also  
470 some overlap between these, particularly between using “green” products and campaigning.  
471 This lends some evidence to general behavioural “positive spillover” (i.e., an increased  
472 likelihood of engaging in one PEB after having engaged in another; Thøgersen, 2012).  
473 Previous findings on positive spillover for PEBs are mixed (Nash et al., 2017). Potential  
474 pathways for positive spillover could be that PEBs (a) serve a common goal; (b) influence  
475 someone towards a “greener” self-perception; (c) cause cognitive dissonance; or (d) increase  
476 learning about environmental issues. The findings also lend evidence specifically to  
477 spillover from “easier” to “harder” behaviours, which has been observed before and appears  
478 to be mediated by perceived self-efficacy (Lauren et al., 2016). But the question remains

479 why a person starts with one of these behaviours in the first place. Centrality can provide  
480 some clues to this as behaviours with more connections may be “entry behaviours” from  
481 which other behaviours follow. This also raises the question whether observation of traces  
482 can be entry points—that is, whether observing a trace of a behaviour makes engagement  
483 in this behaviour more likely. As our data is cross-sectional, this cannot be answered.  
484 However, subjective reports of participants suggests that the causal direction is from traces  
485 to behaviours, rather than from behaviours to traces. This is also substantiated by traces  
486 having (at least numerically) higher indices of centrality, meaning that, on average,  
487 noticing a trace makes it more likely that other traces are observed *and* behaviours are  
488 engaged in, rather than the other way round.

489         Secondly, the second most frequently reported behaviour “Turn off lights”, is mainly  
490 caused by “Lights on” but also by “Lights off”. This is in contrast to previous studies that  
491 looked at how likely it is that people leave the lights on (off) depending on whether they  
492 were on (off) before entering a room (Bergquist & Nilsson, 2016; Dwyer et al., 2015; Oceja  
493 & Berenguer, 2009). Here the opposite is reported: Lights that are left on prompt  
494 participants to switch them off. This may indicate that people are not always aware of  
495 when or how they are influenced by behavioural traces. Perception of behavioural traces  
496 may be “more automatized . . . and thus result in corresponding behaviors with less  
497 conscious processing” (Bergquist et al., 2019, p. 13).

498         Finally, all partial correlations between traces were positive. In other words,  
499 noticing any trace (either pro- or anti-environmental) makes it more likely to notice other  
500 traces. This could be an effect of individual differences in attention: There is considerable  
501 and significant variation between individuals with regards to whether moving/touched  
502 objects are attended to (De Haas et al., 2019), with the implication that some people may  
503 be more prone to attend to behavioural traces than others. Again, people may not be  
504 aware of this tendency. This lack of awareness is not necessarily a “bad” thing: For one,  
505 not having to actively seek and perceive traces may be an advantage to coordinate more

506 effortlessly (Parunak, 2005). Also, reactions to behavioural traces may be “driven by  
507 nonconscious imitation” and are therefore “less susceptible to anti-conformity and  
508 reactance” because “people are less likely to identify a sender” (Bergquist et al., 2019, p.  
509 3). As one participant wrote: “if [I] see people [I] dislike doing something, it makes me  
510 much less likely to do it myself”. Traces are generally divorced from social appearance; they  
511 do not carry the type of information enabling the observer to decide whether one likes or  
512 dislikes the person causing it. Behavioural traces are thus arguably more effective than  
513 direct communication, especially when created as a by-product of a PEB (so-called  
514 *sematectonic traces*; Dipple et al., 2014; Marsh & Onof, 2008).

### 515 **Survey 3 - Inferring Behaviours From Behavioural Traces**

516 A behavioural trace (e.g., a bike parked outside a building) offers an opportunity to  
517 act in a certain way (e.g. cycle to work or school), particularly if the constituting behaviour  
518 can be inferred when confronted with just the behavioural trace. This is especially true for  
519 new or uncommon behaviours—which PEBs often are. Also, one and the same trace can in  
520 theory have been produced by different circumstances (e.g., many blankets in someone’s  
521 home could be an indicator that the house is badly insulated, or it could be an interior  
522 design choice). The goal of Survey 3 was thus to (a) determine whether people could infer  
523 the constituting behaviour just from knowing the trace, as well as (b) which motivations  
524 they suspected behind the most likely behaviour they inferred. Being able to infer the  
525 behaviour and the reasons behind the behaviour makes it easier for people to choose to  
526 engage in this behaviour as well.<sup>7</sup>

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<sup>7</sup> Note, however, that this does not apply to all behaviours. For instance, a route that has often been walked (the behaviour) will show a path (trace). The path will often be easier to walk for newcomers than the surrounding high meadow, independent of whether they can infer the causing behaviour or the motivation behind the behaviour.

## 527 **Methods**

### 528 *Participants*

529 A total of 35 participants were recruited from Prolific. All participants were UK  
530 residents (62% female, age  $M = 38$ ,  $SD = 13.05$ ), and received £0.15 for participation and  
531 a bonus of £0.05 for each meaningful response to open-ended questions. The survey had  
532 approval from the UCL Research Ethics Committee.

### 533 *Materials*

534 We used the same behavioural traces presented in Surveys 1 and 2.

### 535 *Procedure*

536 The survey was hosted on Qualtrics (www.qualtrics.com) and presented in two  
537 parts. In the first part, a trace, described as “evidence of behaviour”, was displayed one at  
538 a time and participants were asked to list up to three realistic behaviours that could have  
539 caused this trace. In the second part, the trace was displayed again, this time with the  
540 causing behaviour participants had entered in the first part. Then participants were asked  
541 to give a realistic reason why someone would engage in this behaviour. The exact wording  
542 for the instructions are in the *Supplementary Materials*. Upon completion, participants  
543 were thanked and debriefed.

### 544 *Data analysis*

545 The open field answers were coded as “*corresponds*” if they matched the behaviour  
546 they initially referred to, “*corresponds in principle*” if the participant did not directly  
547 mention the behaviour but the idea behind it, or “*does not correspond*” if it referred to an  
548 entirely different behaviour. For instance, the behaviour “Uses disposable products (e.g.,  
549 paper/plastic/styrofoam mugs, food containers, cutlery, . . .)” was presented as the trace  
550 “A disposable or single-use item such as a paper mug or a plastic take-out container”. A

551 *corresponds* answer might be “Someone has purchased a take-away coffee from a coffee  
552 shop”, a *does not correspond* answer might be “The container could have been re-used and  
553 washed up”, and an answer that *corresponds in principle* might be “A demand was created  
554 for a take-away item”. The first author rated all items; a group of five additional raters  
555 categorised a fifth of the items each. There was disagreement in 45.90% cases; this is a  
556 combination of 7% cases where one rater said “*corresponds*” and the other “*does not*  
557 *correspond*”, 16.50% cases were one said it “*corresponds*” and the other that it “*corresponds*  
558 *in principle*”, and 21.30% cases were one said it “*does not correspond*” and the other that  
559 it “*corresponds in principle*”. Where there were discrepancies in the rating, the remaining  
560 four raters voted independently for one of the two ratings. Most cases were resolved this  
561 way with 8.50% that could not be agreed upon; these were excluded from analysis.

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

## 572 **Results**

### 573 *Inference of behaviours from traces*

574         In Survey 3, participants provided 516 possible causing behaviours for the traces  
575 presented to them. Of those, 20 were only one-word responses or short phrases that did not  
576 clearly refer to a behaviour and were thus excluded. Although we aimed to obtain an equal

577 number of responses for all traces, this was complicated by the fact that some people  
578 returned the survey unanswered and participants were not required to answer all (or even  
579 any) items. Each trace received between 4 and 11 responses.

580 Of all responses, 128 (24.80%) were rated as *corresponds* to the behaviour, 139  
581 (26.90%) were rated as *corresponds in principle*, and 205 (39.70%) were classified as *does*  
582 *not correspond*. Although all behaviours were coded as *corresponds in principle* at least  
583 once, a total of 14 traces had no behaviour that was rated as *corresponds*. Two traces were  
584 always recognised as produced by the initial behaviour, these were “Double or treble glazed  
585 windows in someone’s home” and “An appliance that is unplugged when not in use  
586 (e.g. stand-by light is off, room is quiet)”. Full results can be found in the *Supplementary*  
587 *Materials*.

588 As expected, the order of the answers mattered. In a multinomial logistic regression  
589 that uses *does not correspond* as the baseline category, both *corresponds*,  $z = 6.33$ ,  $p <$   
590  $.001$ , and *corresponds in principle*,  $z = 4.32$ ,  $p < .001$ , were more likely than *does not*  
591 *correspond* as the first answer compared to the remaining answers. They are, however, no  
592 more likely than *does not correspond* as the second compared with the third answer, with  $z$   
593  $= 0.70$ ,  $p = .481$  for *corresponds* and  $z = 1.53$ ,  $p = .127$  for *corresponds in principle*,  
594 respectively. This means that the original behaviour is likely to be the first that comes to  
595 mind, compared to possible alternative behaviours.

### 596 ***Inference of reasons for behaviours from traces***

597 Participants reported 137 reasons for why the behaviours they inferred from the  
598 traces were performed. We analysed only the 87 reasons for behaviours rated as  
599 *corresponds* or *corresponds in principle*. Table 3 lists the frequency of themes and  
600 sub-themes for external and internal reasons, respectively. Internal reasons are mentioned  
601 more often (79.31%) than external reasons (17.20%). Overall, the most frequent reason is  
602 “Altruism: Benefit climate / environment” (21.80%), followed by “Self-interest: Money

603 saving” (20.70%), with a shared third place for “Self-interest: Convenience / avoid effort”  
 604 and “Self-interest: Enjoyment” (6.90% each). A closer look shows that all “Benefit climate  
 605 / environment” were in response to pro-environmental behaviours (100%). “Money  
 606 saving”, in contrast, was given as a reason for both pro- (29.30%) and anti-environmental  
 607 behaviours (13.80%).

**Table 3**

*Motivations participants assumed to be behind the behaviours they inferred only from traces (Survey 3).*

Area	Theme	Subtheme	Frequency
External	Circumstances / chance	-	7
		Physical	Design of item or environment
		Time constraints	1
	Social	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
		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	

## 608 Discussion

609 All behaviours could at least in principle be inferred from the presented behavioural  
 610 traces. As can be expected, *corresponds* and *corresponds in principle* ratings were more



611 frequent than *does not correspond* among first responses compared to second and third  
612 responses. However, we do not know *how strongly* people endorsed the behaviours they  
613 generated. Another study could follow up on this, presenting the trace and letting people  
614 rate various possible behaviours (including the original behaviour and behaviours generated  
615 from this survey alongside decoys). Interestingly, despite 60.5% of the original behaviours  
616 being pro-environmental, only 21.8% of the behaviours generated were explained through a  
617 motivation to protect the environment. That is, although people could generally infer the  
618 behaviour from the trace, they did not always infer pro-environmental motives as being  
619 behind the behaviour. In the absence of knowledge about the actor, people may project  
620 their own motives onto others (Malle, 2011). If this is the case, self-interested benefits such  
621 as “money saving” are an important motivator behind PEBs in our sample. Self-interest  
622 and altruism can both increase the motivation to engage in PEBs depending on individual  
623 motives and may thus be complementary pathways to increased PEBs (De Dominicis et al.,  
624 2017).

## 625 **General Discussion**

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

634 There are a number of cognitive biases that influence whether someone behaves  
635 pro-environmentally, such as *discounting the future* (e.g., foregoing future benefits of home  
636 insulation due to current costs, even though the cumulative benefits outweigh in the long

637 run) or *positive illusions* (i.e., the tendency to see the future in a more positive light than  
638 is objectively warranted, thus abstaining from mitigating action; Shu & Bazerman, 2010).  
639 Some of these biases may be mitigated by the presence of behavioural traces and could  
640 explain why observing a trace increases the odds of engaging in the related behaviour.  
641 Gifford and Nilsson (2014) for instance highlight the *false consensus effect*, whereby people  
642 who strive to maximise their gains at the environment's expense are more likely to believe  
643 that others will do the same (Gifford & Hine, 1997). This cognitive bias is harder to  
644 maintain in the presence of evidence of others engagement in PEBs. With behavioural  
645 traces of PEBs present, it may be harder to (falsely) believe that others share one's  
646 intentions, perhaps prompting the actor to reconsider their selfish choices. Similarly, the  
647 *self-serving bias* (or *egocentrism bias*; Shu & Bazerman, 2010) leads us to take credit for  
648 any good we do (e.g., behave pro-environmentally) but deny any blame for the bad we do  
649 (e.g., behave anti-environmentally)—or at least take more credit and less blame than we  
650 grant others (*reversed actor-observer effect*; Gifford & Nilsson, 2014). However, we may  
651 find it harder to make excuses for our anti-environmental choices when confronted with the  
652 hard evidence of our choices such as behavioural traces of our own actions, making it less  
653 likely that the self-serving bias is maintained. Nevertheless, the possible effect of  
654 behavioural traces may still be undermined by the *negative footprint illusion*: when a  
655 “green” choice is offered in addition to other options, the total footprint is perceived as  
656 lower, even though in fact it must be higher because of the additional, albeit “green”, item  
657 (Holmgren et al., 2018). However, the results stem from a study using vignettes and may  
658 be different with concrete items. It is thus vital that future studies not only investigate the  
659 cognitions involved when encountering behavioural traces, but study actual behavioural  
660 traces “in the wild”.

## 661 **Limitations and Future directions**

662 One intentional limitation is that we only report substantial effect sizes so that  
663 results of the network analysis are conservative and should not include many false  
664 positives. It is thus possible that we missed existing relations between behaviours and  
665 traces. Focussing on only a small set of behaviours and their traces, as well as experimental  
666 setups in- or decreasing the number of traces and observing their impact on behaviours,  
667 may be needed to get a fuller picture of the direction and strength of these relations.

668 The initial selection of PEBs was chosen to portray behaviours previously  
669 considered as important, but this may have neglected behaviours that have recently  
670 increased in importance or were overlooked in the past. Additional behaviours and their  
671 traces should be considered in future research. Similarly, half of the sample in Survey 1  
672 were recruited from a student population. Although many mentions of traces were  
673 excluded as duplicates, leading us to think we reached a saturation point for the  
674 behaviours considered, a sample drawn from a different context may have delivered  
675 additional unique traces. Since this study focused on traces in the UK, understanding  
676 which behaviours link to which traces would need to be repeated in different countries.

677 Many studies regarding PEBs—including the present—rely on self-report measures.  
678 These are not entirely reliable—only 79% of variance in actual behaviour is explained by  
679 self-report measures (Kormos & Gifford, 2014). In addition, people may overestimate how  
680 pro-environmentally they behave compared to others (Bergquist, 2020). Similarly, people  
681 may not be able to accurately report behavioural traces encountered if the measure is, for  
682 instance, not immediate and sensitive enough (Newell & Shanks, 2014). It is therefore  
683 desirable to use actual behaviour as the outcome measure in future research and, where  
684 possible, manipulate or control for features of behavioural traces.

685 Another limitation of the design of this study is that it does not allow us to draw  
686 conclusions about causality. People may already be engaging in the behaviour and as a

687 result encounter other people's traces more often; or, participants may encounter other's  
688 traces and therefore explore the behaviour. When asked about their own estimation  
689 whether traces would decrease or increase their behaviours, they expect seeing a new trace  
690 to increase the related behaviour. By contrast, once a behaviour is adopted, they expect  
691 that seeing the related trace never again would have little impact. This indicates that  
692 behavioural traces may be a source of learning about new behaviours, but have little  
693 impact on the maintenance of that behaviour. Most likely, the relation between traces and  
694 behaviour is a dynamic one that depends on a number of other factors, such as the  
695 *frequency*, *number* and *type* of traces encountered. Someone not currently engaging in a  
696 behaviour may become aware of the behaviour through traces that are frequent, numerous,  
697 or otherwise highly salient. As they start engaging in the behaviour, they would likely  
698 encounter related traces even more often, for instance if they start commuting by bicycle  
699 and therefore encounter more cycling-related traces. Whilst this is plausible, additional  
700 research is required to ascertain the direction of this relation, ideally longitudinally.  
701 Alternatively, future research could focus on specific behaviours and their traces in a more  
702 controlled design to shed light on the causal direction between traces and behaviours.

703         Here we focused on how often traces are encountered, ignoring whether many traces  
704 were created by few people, or few traces were created by many people. However, it may  
705 be interesting to investigate whether the effect of traces is moderated by who created them.  
706 For instance, one bike left outside the building every single day in rain, sunshine or snow  
707 may signal a different level of commitment compared to many bikes left on sunny days only  
708 (the number of commutes by bike and thus energy saved being equal).

## 709 **Implications**

710         Widespread adoption of PEBs will be necessary to avert the worst of the climate  
711 crisis (Dietz et al., 2009), be that voluntary as bottom-up action or through policy changes  
712 as top-down requirements. For the large group of conditional cooperators (Fischbacher et

713 al., 2001), seeing behavioural traces of PEBs could increase their willingness to engage in  
714 PEBs themselves. From behavioural traces we cannot know whether a majority creates a  
715 few traces, or whether a small but dedicated group creates many traces. Thus behavioural  
716 traces provide a less certain picture about what the majority of other people are doing  
717 than, for example, the information that “X% of people engage in behaviour Y”—the way  
718 descriptive social norms are often communicated. But perhaps conditional cooperators do  
719 not need to know that a *majority* of people engage in PEBs. What counts is the  
720 cumulative impact, not the number of contributors, and behavioural traces can capture  
721 this information very well. For instance, a hundred lightbulbs being switched off means 100  
722 times savings – it does not matter whether one person switched all of them off or a  
723 hundred people switched off one each. In fact, a small dedicated group may even have a  
724 higher total impact than a less dedicated majority. Assuming average carbon footprints,  
725 the impact one person can make by stopping to fly equals 15 people dedicated to perfect  
726 paper recycling (MacKay, 2008). Only knowing the descriptive norms of both behaviours  
727 would then actually be detrimental to impactful (conditional) cooperation. Behavioural  
728 traces *and* beliefs of descriptive social norms in tandem could of course have an even larger  
729 effect on behaviour than each on their own. However, additional research is needed as to  
730 when frequent behavioural traces are perceived as a descriptive norm to be able to separate  
731 their effects.

732 Individual action is but one side of the coin, however. Bendor and Mookherjee  
733 (1987) demonstrate that although decentralised conditional cooperation (we imagine, for  
734 instance, through behavioural traces) is only superior in conditions with perfect  
735 information about the relationship between individual actions and collective benefits,  
736 decentralised conditional cooperation can nevertheless supplement centralised coordination  
737 of collective action. Most likely, new policies will be adopted more quickly if they are  
738 introduced when a critical number of people already engage in related behaviours. The  
739 near global ban or tax on single-use plastic bags is a case in point (Clapp & Swanston,

740 2009). While more research is needed to fully understand the relation between behaviours  
741 and their traces, we can show that there are meaningful links between noticing a  
742 behavioural trace and engagement in related behaviours. In terms of interventions, the  
743 following approach may thus be promising: (1) encourage those who already engage in  
744 PEBs so that they continue to produce the related traces, and (2) visually highlight or  
745 otherwise emphasize the resultant behavioural traces while (3) making anti-environmental  
746 traces less salient. Together, this could directly and indirectly increase awareness of the  
747 behaviours as well as the number of people engaged in these behaviours.

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1026

**Supplementary Materials - Instructions****Instructions for Survey 1**

1028 In the following, we will show you a number of behaviours. Some of them are  
1029 pro-environmental behaviours (i.e., they help protect the environment or conserve energy),  
1030 others will be related behaviours.

1031 For each behaviour, we would like you to list traces for this behaviour. A  
1032 behavioural trace is any physical evidence or artefact of that behaviour, but not the  
1033 behaviour itself. Note that traces are generally objects but also include noises, smells and  
1034 digital evidence (e.g., websites). For example, when you think of cycling, behavioural  
1035 traces could be

- 1036 • a bike chained to a rail outside your home or workplace
- 1037 • bike sheds
- 1038 • a marked-up cycling lane
- 1039 • bikes and related accessories (e.g., helmets) sold in shops
- 1040 • advertisements for cycling schemes at work or in the media
- 1041 • . . .

1042 Please generate as many behavioural traces as you can think of. You may find it  
1043 easier to list traces for some behaviours and harder for others. It is entirely up to you in  
1044 which order you answer and how much time and effort you would like to spend on this. It  
1045 is fine to leave text fields empty if you cannot think of any traces.

***Instructions for Survey 2***

1047

**Behaviours**

1048 In this section we would like to find out how often you engage in a number of  
1049 behaviours. Please select what best represents your typical behaviour. How often do you:  
1050 *Answers: Never - Rarely - Sometimes - Often - Always*

## Traces

In this part, we would like to know how often you see evidence of other people's behaviour. By this, we DON'T mean how often you actually SEE other people DO things. Instead, we want to know **how often you notice traces that are the result of other people's behaviour**. In the last three months, how often did you notice: *Answers: Never - Not in the last three months - Once or twice - About monthly - About weekly - Several times a week - About daily*

## Validation

Earlier in this survey you saw a long list of traces (evidence of behaviour). Think of a time when seeing traces made you change your behaviour.

Please give specific examples of when seeing traces increased your own behaviour (i.e., because you saw traces, you did something more often): *Open answer*

Please give specific examples of when seeing traces decreased your own behaviour (i.e., because you saw traces, you did something less often): *Open answer*

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? Would you do the related behaviour: *From 0 (less often) to 100 (more often)*

From the list of traces, think of traces that you have never seen before. Do you think that if you suddenly saw them daily would it change your behaviour? Would you do the related behaviour: *From 0 (less often) to 100 (more often)*

## 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**

1075 **could have caused this piece of evidence.**

1076 For example: **Evidence** = A bike chained to a railing outside the workplace.

1077 **Possible causing behaviour 1** = Someone cycled to work. **Possible causing**

1078 **behaviour 2** = Someone drove the bike there in a van. **Possible causing behaviour 3**

1079 = Someone pushed the bike walking to work.

1080 **For each meaningful response, you will get a bonus payment of £0.05.**

1081 That is, the more behaviours you list, the higher your overall payment. Note that only  
1082 realistic behaviours count (e.g., in the example above, “an alien having beamed the bike  
1083 there” would not count). Please be as clear and precise as possible. If we cannot make  
1084 sense of your answer, it will not count towards your bonus payments. Once submitted, you  
1085 won’t be able to amend your answer later.

1086 Altogether, **you will see five pieces of evidence.**

1087 If you have any questions before you start, please contact the experimenter through  
1088 prolific.co.

1089

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## 1090 *Part 2*

1091 In the following, **you will see some of the behaviours you listed earlier.**

1092 For each behaviour, **we would like you to list possible motivations why**  
1093 **someone would engage in this behaviour.**

1094 For example: **Behaviour** = Someone cycled to work. **Possible motivation 1** =  
1095 Cycling is cheaper than other transport options. **Possible motivation 2** = Cycling is  
1096 healthier than other transport options. **Possible motivation 3** = The person cycling is  
1097 training for a triathlon and this is part of their practice.

1098           **Again, for each meaningful response, you will get a bonus payment of**  
1099 **£0.05.** That is, the more motivations you list, the higher your overall payment. Note that  
1100 only realistic motivations count (e.g., in the example above, “Cycling makes the clouds go  
1101 pink” would not count). Please be as clear and precise as possible. If we cannot make sense  
1102 of your answer, it will not count towards your bonus payments. Once submitted, you won’t  
1103 be able to amend your answer later.

1104           **You will see up to five behaviours (fewer if you did not list behaviours in**  
1105 **the first part of the study). If you did not name any behaviours, the next page**  
1106 **will be empty. It is fine to list similar or the same motivations for different**  
1107 **behaviours if that is meaningful.**

1108           If you have any questions before you start, please contact the experimenter through  
1109 prolific.co.

1110

## Supplementary Materials - Frequencies

## 1111 Frequency of behaviours

Table 4

*Mean and SD for frequency of behaviours engaged in (Survey 2).*

Behaviour	Behaviour Short	M	SD
Recycle items that can be recycled (e.g., glass, paper, plastic, aluminium)	Recycle	4.4	4.42
Try not to waste food (e.g. by using leftovers)	FoodWaste	4.3	4.29
Shop or order things online	ShopOnline	3.7	3.70
Boil only the amount of water you need (e.g., when using a kettle or cooking)	BoilWater	3.5	3.55
Walk for shopping and other errands	WalkShop	3.5	3.51
Takes steps to reduce water use	WaterUse	3.4	3.38
Educate yourself about topics related to sustainability and climate change	Learn	3.2	3.19
Turn off the TV and other appliances completely (i.e., do not keep them in standby mode)	ApplianceOff	3.2	3.22
Repair a broken item (e.g. computer, phone, household appliance)	Repair	3.2	3.18
Buy items with less packaging or shop zero waste	LessPackaging	3.0	3.01
Replace a traditional appliance with an energy efficient appliance (e.g., fridge, printer, washing machine)	EffAppliance	2.9	2.85
Buy a new item (e.g., clothes, luxury items) (R)	NewItems	2.9	2.90
Buy an environmentally friendly product (e.g. 'green' cleaning products, organic cotton)	GreenProducts	2.9	2.94
Drive for shopping and other errands (R)	DriveShop	2.9	2.92
Compost food and kitchen waste	Compost	2.9	2.91
Walk to school, university or work	WalkWork	2.8	2.75
Use disposable products (e.g., paper, plastic or styrofoam mugs and food containers) (R)	SingleUseProd	2.8	2.76
Leave the heating on in a room you're not using (R)	HeatingOn	2.5	2.55
Take a plane for holidays and leisure trips (not counting flying for work) (R)	Fly	2.5	2.52
Use single-use plastic shopping bag (R)	SingleUseBag	2.5	2.47
Use conventional light bulbs (R)	ConventionalLights	2.4	2.42
Drive to get to school, university or work (R)	DriveWork	2.4	2.43
Leave the lights on in a room you're not using (R)	LightsOn	2.2	2.23

**Table 4**

*Mean and SD for frequency of behaviours engaged in (Survey 2). (continued)*

Behaviour	Behaviour Short	M	SD
Install additional insulation in your home	Insulation	2.0	2.00
Do something together with others to address an environmental issue (e.g., set up recycling scheme)	EnviroScheme	1.9	1.89
Avoid information about topics related to sustainability and climate change (R)	AvoidInfo	1.8	1.77
Donate or invest money in a pro-environmental project	Donate	1.8	1.79
Install a more efficient heating system	HeatingSystem	1.8	1.78
Turn on air-conditioning (R)	AirCondition	1.7	1.66
Take part in a campaign or protest about an environmental issue	Campaign	1.6	1.58
Live in, build or buy an energy-efficient home (e.g. passive house)	EffHome	1.6	1.58
Cycle for shopping and other errands	CycleShop	1.6	1.59
Complain about or resist an environmental scheme (e.g., at school or the workplace) (R)	Complain	1.5	1.49
Cycle to school, university or work	CycleWork	1.5	1.55
Discourage other people from being more pro-environmental (R)	Discourage	1.3	1.32
Drive an electric car	ElectricCar	1.1	1.13

1112 **Frequency of traces**

**Table 5**

*Mean and SD for frequency of traces encountered (Survey 2).*

Trace	Trace Short	M	SD
A car parked outside school, university, work or shops (R)	CarParked	6.2	1.30
A delivery van outside someone's home	DeliveryVan	5.9	1.22
The car brand or logo of a petrol or diesel car (R)	PetrolCarLogo	5.7	1.75
Someone having or carrying a reusable shopping bag (e.g., in purse, at home or in car boot)	ReusableBag	5.6	1.26
A re-usable item such as a mug/cup, water bottle, lunch container, fabric bag	ReusableItem	5.6	1.51
Someone having car keys (e.g., on their key ring) (R)	CarKeys	5.5	1.66
Someone having cycling gear (e.g., helmet, clothing, lights, and other accessories)	CyclingGear	5.4	1.46
A bicycle parked outside school, university, work or shops	BikeParked	5.3	1.66



**Table 5***Mean and SD for frequency of traces encountered (Survey 2). (continued)*

Trace	Trace Short	M	SD
Water still left in a shared kettle after use (R)	WaterInKettle	5.2	1.91
Packaging such as cardboard boxes or bubble wrap from an online delivery	PackagingDelivery	5.2	1.32
An energy-efficient light bulb visible in the fitting	EffLightbulb	5.1	1.96
A recycling bin being set out on council collection days	RecycCollect	5.0	1.25
A disposable or single-use item such as a paper mug or a plastic take-out container (R)	DisposableItem	5.0	1.60
Someone having or carrying a single use shopping bag (R)	DisposableBag	4.9	1.61
Packaging in bins (e.g. at school, university or work; or at the curb on council collection days) (R)	Packaging	4.8	1.60
Double or treble glazed windows in someone else's home	DoubleGlazedW	4.7	2.03
An environmentally friendly or 'green' product (e.g., reusable items, solar chargers, organic food, green cleaning products)	GreenProduct	4.6	1.63
Dedicated recycling bins in someone's home	PrivateRecycling	4.6	1.92
A solar panel on someone's house	SolarPanel	4.5	1.81
That the lights were on when you entered an empty room (R)	Lights	4.5	1.80
Someone at school, university or work wear waterproof or weather appropriate clothing	Weatherproof	4.5	1.80
Food leftovers in a container (e.g., in a shared fridge at work)	FoodLeftovers	4.5	1.99
Food stored in re-usable containers or re-usable containers ready for shopping	ReusableContainer	4.4	1.91
Social media posts about or likes of articles about sustainability and climate change	SocMediaArticle	4.2	1.77
An appliance that is unplugged when not in use (e.g. stand-by light is off, room is quiet)	ApplianceIsOff	4.2	2.00
The car brand or logo of an electric vehicle	EcarLogo	4.2	1.82
That someone's appliance (e.g., computer, phone) look well-used or outdated	UsedDevice	4.1	1.72
Someone having the newest appliance on the market (e.g., computer, phone) (R)	NewDevice	4.1	1.68
Holiday photos (e.g., on social media), souvenirs, or postcards from a flight destination (R)	FlightPhotos	4.1	1.72
Pro-environmental messages (e.g., on posters, stickers, t-shirts or tote bags)	PosterSticker	4.0	1.64
Someone driving with their windows closed on a hot day (R)	CarWindowClosed	4.0	1.76

**Table 5***Mean and SD for frequency of traces encountered (Survey 2). (continued)*

Trace	Trace Short	M	SD
A caravan or motor home	Caravan	4.0	1.58
A single-use shopping bag in the bin (R)	DisposableBagBin	4.0	1.72
Social media posts about or likes of a pro-environmental project or campaign	SocMediaCampaign	3.8	1.73
A solar heating panel on someone's house	SolarHeating	3.8	1.94
That a radiator is switched on when no one is using the room (R)	Heating	3.8	1.95
Holiday photos (e.g., on social media), souvenirs, or postcards from a nearby destination	ClosePhotos	3.8	1.62
A private charging point for electric vehicles	PrivateEcarCharger	3.8	1.89
Books, magazines, leaflets or documentaries about sustainability or climate change	Books	3.7	1.57
A conventional light bulb visible in the fitting (R)	ConvLightbulb	3.7	1.93
Lights on a timer switch or with a motion sensor	AutomaticLights	3.6	2.05
Empty boxes of new items such as shoes or electrical gadgets (R)	NewBox	3.6	1.56
Comments criticising pro-environmental behaviour (e.g. on social media) (R)	CriticalComments	3.5	1.78
An almost-as-new item in second-hand shops (R)	New2ndHand	3.5	1.52
Packaging (e.g. boxes) of large appliances after delivery (e.g. fridge, washing machine)	PackagingAppliance	3.3	1.47
A compost bin in someone else's garden	PrivateCompost	3.3	1.69
A rain water collection system in place (e.g., a water butt)	RainCollection	3.3	1.94
A car loaded with holiday gear (e.g., bicycles, canoes, skis)	CarHoliday	3.2	1.26
A compost caddy or replacement bags in someone else's kitchen	KitchenCompost	3.2	1.75
An air-conditioning unit and/or controls for the unit in the room (R)	AirConUnit	3.0	1.79
The noise of an air-conditioning unit (R)	AirConNoise	3.0	1.65
An automatically stopping water tap	AutomaticTap	2.9	1.96
Single-glazed windows in someone else's home (R)	SingleGlazedW	2.9	1.64
A large suitcase on a train	SuitcaseTrain	2.9	1.43
Signatures already on a petition list for a pro-environmental issue (online or on paper)	PetitionSign	2.8	1.50
Donations to pro-environmental projects or organisations on a crowdfunding website	Donations	2.7	1.51
A large appliance (e.g. fridge, washing machines) being collected for disposal	DisposedAppliance	2.7	1.24

**Table 5***Mean and SD for frequency of traces encountered (Survey 2). (continued)*

Trace	Trace Short	M	SD
Someone wearing mended clothes	MendedClothes	2.7	1.45
An almost-as-new item in waste bins (R)	NewItemBin	2.7	1.50
News, books or magazines that doubt climate change	NewsDoubt	2.6	1.48
A disposed of appliance (e.g., computer, phone etc.) in the tip or ready for council collection (R)	DeviceDisposed	2.6	1.37
Someone's luggage tagged with a flight number (R)	FlightTag	2.6	1.27
Building works to retrofit insulation (e.g., insulation material on a building site)	InsulationFit	2.5	1.41
A warm floor from radiant floor heating	RadiantFloor	2.4	1.49
Books and magazines about energy efficient building	BuildBook	2.3	1.40
Torn-up flyers about a pro-environmental campaign (R)	TornFlyer	1.9	1.27

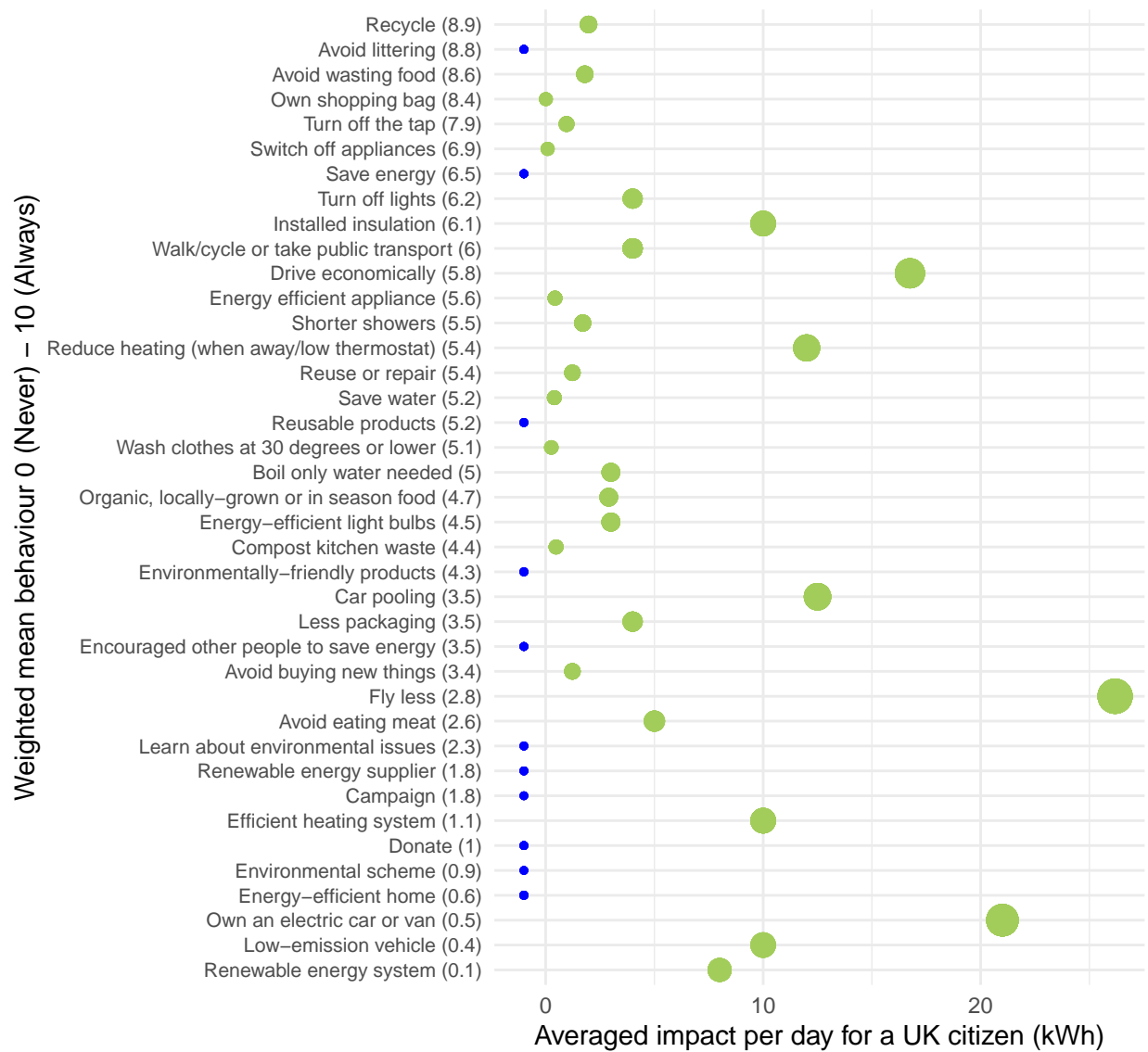
## Supplementary Materials - Impact

1113

### 1114 **Impact of behaviours**

1115 We also assessed the impact of each PEB based primarily on MacKay (2008) and  
1116 where necessary other sources (Anglian Water, n.d.; Automobile Association, n.d.; BBC,  
1117 2011; BIO Intelligence Service, 2011; Civil Aviation Authority, 2016; Fat Knowledge  
1118 (Blog), 2007; Standford University, n.d.; University of Wisconsin-Madison, n.d.; Weideli,  
1119 2013; Wikipedia, n.d.; WRAP, 2017). Comparisons of impacts are difficult because PEBs  
1120 vary widely in type of energy needed and typical frequency. In line with MacKay (2008),  
1121 we transformed all energy use to kWh and calculated *typical UK consumer use per day*.  
1122 For instance, the average UK citizen takes 0.3 domestic, 0.6 EU flights and 0.3  
1123 intercontinental flights per year. To calculate the impact of these flights of the average user  
1124 per day, their kWhs are summed and divided by 365 days. Note that a limitation is that  
1125 the lifecycle of a product was generally not considered for simplicity. For example, to  
1126 determine the environmental impact of trading a petrol for an electric car, we should  
1127 ideally also consider the energy used to produce all materials involved to make the new car.  
1128 However, this is practically impossible. The impact of some behaviours (e.g., “Avoid  
1129 littering”) was not determined because although they may have an environmental impact  
1130 in terms of wildlife, they do not use energy. Once a snack wrapper has been produced, it  
1131 does not use more energy whether it sits in a landfill or in a ditch. The impact of other  
1132 PEBs was not determined because they were too vague (e.g. “Vote”, “Campaign”,  
1133 “Petition”), even though they have a potentially much higher impact than individual  
1134 behaviours could have *if* they lead to policy changes. Other items such as “Alternative to  
1135 travelling, e.g. by shopping online” may actually increase energy use if this means delivery  
1136 vans replace someone picking up an item on the way home or if they are travelling via a  
1137 more sustainable mode.

### 1138 **Prevalence and impact**



**Figure 5**

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