

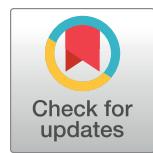
RESEARCH ARTICLE

Effects of environmental impact labels on the sustainability of food purchases: Two randomised controlled trials in an experimental online supermarket

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Abstract

Providing consumers with product-specific environmental impact information for food products (ecolabels) may promote more sustainable purchasing, needed to meet global environmental targets. Two UK studies investigated the effectiveness of different ecolabels using an experimental online supermarket platform. Study 1 (N = 1051 participants) compared three labels against control (no label), while Study 2 (N = 4979) tested four designs against control. Study 1 found significant reductions in the environmental impact score (EIS) for all labels compared to control (labels presented: values for four environmental indicators [-3.9 percentiles, 95% CIs: -5.2, -2.6]; a composite score [taking values from A to E; -3.9, 95% CIs: -5.2, -2.5]; or both together [-3.2, 95% CIs: -4.5, -1.9]). Study 2 showed significant reductions in EIS compared to control for A-E labels [-2.3, 95% CIs: -3.0, -1.5], coloured globes with A-E scores [-3.2, 95% CIs: -3.9, -2.4], and red globes highlighting 'worse' products [-3.2, 95% CIs: -3.9, -2.5]. There was no evidence that green globes highlighting 'better' products were effective [-0.5, 95% CIs: -1.3, 0.2]. Providing ecolabels is a promising intervention to promote the selection of more sustainable products.

Introduction

There is an urgent need to move towards more sustainable diets to mitigate climate change, biodiversity loss, water pollution, unsustainable water use, and other harmful impacts of the current food system on the natural environment [1]. The environmental impacts of different types of foods are highly variable, with up to a 200-fold difference in impact between protein-rich foods (such as beef versus tofu), and 50-fold difference between the same product offered by different producers [2]. However, a lack of product-specific environmental information

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means that consumers have no easy way to differentiate between more and less sustainable products.

For consumers to be able to make environmentally informed purchases, they need relevant information about the environmental impacts of individual food products at point of choice. Health-related nutrition labelling on foods is now widely implemented, with research showing such labels lead to changes in consumer purchasing and consumption behaviours, for example by reducing purchasing of energy-dense food and drinks and increasing purchasing of items with claimed health-related benefits [3]. Accordingly, one potentially promising approach to encourage more environmentally-sustainable food selection is through the use of environmental impact labels [4].

So-called 'ecolabels' typically consist of claims, warnings, or information provided with a product advising consumers about the quality, features or production methods that reduce or increase environmental impacts [5]. One limitation to many of the ecolabels is that they do not capture the environmental impacts from the full lifecycle of food production. Instead, they primarily indicate whether one set of production practices (for example, organic agriculture) or set of standards (for example, Rainforest Alliance) has been applied. However, adoption of certain practices or standards does not necessarily lead to low environmental impacts across multiple indicators [2]. There are increasing societal demands for greater transparency in reporting food production methods that will enable greater precision and accuracy in quantitative ecolabelling [6].

According to the Ecolabel Index, the largest global directory of ecolabels, there are at least 121 ecolabels related to food worldwide [7]. There is great diversity in the type of information conveyed and the contexts within which ecolabels are presented, both of which may impact effectiveness [8]. For example, there are variations in ecolabel formats (e.g. logo vs text only) and the specificity of the information provided (numerical score vs grade vs claim only).

A recent systematic review of 76 ecolabelling interventions found that ecolabels, across a broad range of formats and content types, are effective at promoting the selection, purchase, and consumption of food and drink products [4]. However, the lack of standardized ecolabel formatting and the diversity of labels may create confusion rather than clarity for consumers [9]. In addition, different consumer groups may respond to ecolabels in different ways [10]. Moreover, while studies have shown ecolabels to be effective at altering food purchasing or selection, these have often featured in relatively small numbers of products and/or participants, limiting the ability to examine effectiveness across the basket and different demographic groups [11–13].

This paper describes two experimental proof-of-principle studies that aimed to assess the potential of different environmental impact label designs to effectively promote the selection of lower environmental impact products. These environmental impact labels reflected the broader environmental impact of products, based on Life Cycle Assessment (LCA) data and four environmental impact indicators [14], rather than information on specific production practices and standards (as often the case with many current ecolabels). Study 1 explored whether participants who saw product-specific environmental impact labels would select more sustainable food products than those who saw no labels. Study 2 extended Study 1 by comparing effectiveness across environmental impact label designs and assessing differences based on participant characteristics such as meat knowledge and intentions to reduce meat consumption.

Methods

Each study protocol was prospectively registered online (Study 1: ISRCTN Ref. 15655434; Study 2: Open Science Framework <https://osf.io/rwy4k/>). Studies 1 and 2 were reviewed by,

and received ethics approval through, the University of Oxford Central University Research Ethics Committee [R65010/RE001, R65010/RE003]. Informed (written) consent was obtained from all participants.

Participants

Adult participants aged 18 years or over were recruited from an online research platform (Prolific Academic, <https://www.prolific.co>). Panel members who self-identified as vegetarian or vegan (groups that comprise approximately 7% of the UK population [15]) were excluded because some of the products on the shopping list included meat and dairy (given the substantial contribution of these products to the environmental impact from diets) and we wanted to ensure that participants felt able to follow this list when instructed to shop for foods they would be willing to eat. Only English-speaking panel members currently residing in the United Kingdom were eligible.

Study design and interventions

Study 1 was a 2x2 factorial randomised controlled trial (RCT) where participants were randomised to one of four study conditions: 3 intervention (different labels) and 1 control (no label). Each intervention condition tested one of three labels: A-E (a total composite environmental impact score on an A-E scale with a traffic light colours); Petal (displaying four environmental impact values and using text, colour, and “petal” size as cues), and Combined (both A-E and Petal) (see Fig 1; further label details provided below).

Study 2 was a 5-arm parallel RCT in which participants were randomised to one of five study conditions, with 5 participants randomised into an intervention arm for every 2 randomised to the control (no label) group (to power for between-label comparisons). Study 2 tested the A-E label and three further label designs: Globe (A-E scores superimposed on a globe image), Better (green globe image with text stating ‘BETTER’), and Worse (red globe image with text stating ‘WORSE’) (see Fig 1).

Both studies were conducted using an experimental online supermarket platform developed at the University of Oxford. The supermarket was designed to emulate a real online supermarket for research purposes, the key difference being that food/drink selections are not paid for or received. In the absence of a real purchasing context in which different types of interventions can be implemented, this offers a relatively naturalistic setting to assess a range of labelling options. The site was populated with approximately 20,000 supermarket products (including their images, prices and nutritional information) drawn from foodDB (April 2019), an up to date database of food and drink products available for purchase in six UK online grocery retailers [16]. Study 1 was conducted in February 2020; Study 2 in June-July 2020. For Study 2, some additional cleaning of the database was performed, whereby products for which there were multiple similar products (e.g. at different quantities), or “counter” or bakery items without valid data on their nutrient composition available on the supermarket website were removed. The search order for products on the online supermarket was presented in a different random order in the two studies. Data were collected and managed using the supermarket platform and REDCap (Research Electronic Data Capture) tools hosted at the University of Oxford [17, 18]. Participants were electronically randomised (ensuring allocation concealment) using REDCap.

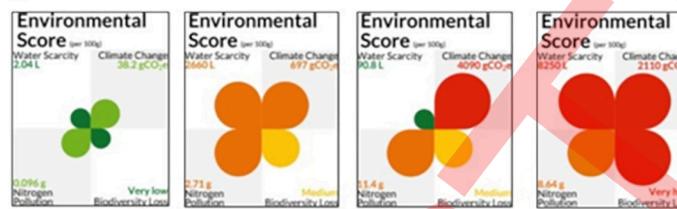
Labels. Environmental impact scores for product labels were generated using the ingredient lists available for each product and were reported per 100g of each product. Information on the ingredients list was used to:

STUDY 1

a.



b.



c.



STUDY 2

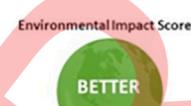
d.



e.



f.



g.



Fig 1. Ecolabels tested in Studies 1 and 2. a) Study 1, A-E label: a total composite environmental impact score on an A-E scale with a traffic light colour gradient with five colours ranging from dark green to dark red; b) Study 1, Petal label: displaying four environmental impact values and using text, colour, and “petal” size as cues; c) Study 1, Combined label: displaying labels a and b, above; d) Study 2, refined A-E label: same A-E label used in Study 1 with smaller descriptive text; e) Study 2, Globe label: a single A-E score centered in a globe image with a five-colour traffic light gradient ranging from dark green to dark red; f) Study 2, ‘Better’ label: a green globe with the text “Environmental Impact Score” above the circle and the word ‘Better’ displayed inside; g) Study 2 ‘Worse’ label: a red globe with the text “Environmental Impact Score” above the circle and the word “Worse” displayed inside.

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1. identify the relative composition of ingredients if available (e.g. 10% ingredient X);
2. estimate the relative composition of ingredients where composition information was not provided, using information from similar products and UK labelling regulations;
3. link each ingredient to a global environmental LCA database; and
4. calculate the environmental impact per 100g of product for four environmental indicators (greenhouse gas emissions, scarcity weighted water stress (hereafter water use), land use related biodiversity loss (hereafter biodiversity loss), and eutrophication potential) based on

the composition of each ingredient, the type of ingredient (e.g. a mushroom, a tomato, or poultry meat), and environmental information in the database.

More information on the derivation of the environmental impact scores is described in detail elsewhere [14].

We did not have access to data on producers for individual products. Rather than assuming the same values for each product (e.g. fresh berries), which would mean that all such products would have the same (or a very similar) environmental impact score, we identified individual producers with environmental performance data equivalent to the 25th percentile (e.g. a more sustainable producer), 50th percentile (e.g. the median sustainable producer), and 75th percentile impacts (e.g. a less sustainable producer) across all producers for that food category and for each environmental indicator. When calculating the environmental impact scores (as described above), we then randomly assigned products to have all their ingredients sourced from a more sustainable producer, a median sustainable producer, or a less sustainable producer. This ensured that there was variability in the environmental impact scores between products within a given product category, and also that the environmental impact scores were based on producer-level environmental performance data rather than, for example, assuming that more sustainable products had a 20% lower environmental impact.

The four environmental indicators were then condensed into a product-specific environmental impact score. To do this, products were ranked based on their percentile score (rather than absolute values for each of the four indicators). To arrive at a single environmental impact score for each product, we then took the mean percentile across the four indicators, and then re-ranked this overall environmental score such that it ranged from 1 (lowest impact product) to 100 (highest impact product) based on the percentile environmental impact score of each product. To obtain A–E grades, we then split the environmental impact score into quintiles, whereby a value of A = an environmental impact score of 1–20, B = 21–40, C = 41–60, D = 61–80, E = 81–100. We placed equal weighting on each environmental indicator because our focus was on assessing consumer responses to different labels rather than deeper exploration of the grading scheme itself.

An individualised logo for each product was created using environmental impact data using an automated script written in R (see [Fig 1](#)). Images (.jpg) of each logo were uploaded onto the virtual online supermarket platform and linked to each individual food product, to be displayed underneath the food product during the experiment.

Labels were developed and refined prior to study launch using insights from focus group sessions with UK adults [19] (see [S2 File](#) for more information on label development). They were displayed on all products, with the exception of the 'Better' and 'Worse' label conditions, when they were displayed on only 20% of products within each food group with the lowest and highest environmental impacts, respectively (see [S1 File](#) for a list of food groups).

Procedure

Following online screening questions to ensure eligibility, participants provided electronic (written) consent. Eligible participants were then directed to the supermarket platform, which participants interact with in the same way as a real online supermarket, but with no money being spent and no items received. In line with previous studies using the experimental supermarket platform [e.g. 20], participants were asked to select groceries from a shopping list covering 10 items, with no set budget (see [S3 File](#) for an example of the welcome screen on the shopping platform). The food items included in the list were chosen because of the wide variation in environmental impact between these categories. The items on the shopping list were as follows:

- A savoury snack for right now
- Milk for everyday use
- A ready meal
- Cheese to use in a sandwich or light meal
- A pizza (fresh or frozen)
- A bar of chocolate
- Nuts for snacking on
- Meat, fish, or vegetarian alternative protein for main meal
- Rice to accompany the main meal
- Berries for dessert (fresh or frozen)

After completing the shopping task, participants were redirected to a post-test survey where they provided basic demographic information, as well as details concerning their household size and online grocery shopping habits (see [S4 File](#)). A free-text response option enabled them to describe their experience using the supermarket. The post-test survey in Study 2 was expanded to include the following measures: i) current hunger and fullness, since increased levels of hunger are associated with increased attention to food cues which could confound the results [21] and food selection has been associated with the feelings of fullness that a product is expected to confer [22], ii) a measure of participants' level of awareness of the effects of meat production on the environment (hereafter: meat knowledge) [23], iii) frequency of meat consumption (hereafter: meat consumption), derived from a short questionnaire to report meat intake over the previous day, and iv) intention to reduce meat consumption (hereafter: meat reduction).

Outcomes

Primary outcome. The primary outcome was the mean environmental impact score (hereafter: EIS) of products placed in the shopping basket. A mean environmental impact score of 1 would mean that only those products with the best environmental impact per 100g (falling into the 1st percentile) were selected, while a score of 100 would mean only those with the worst impact per 100g (falling into the 100th percentile) had been chosen.

Secondary outcomes. Each study had three secondary outcomes. First, we examined the means across products placed in the basket for four individual environmental indicators that the environmental impact scores were based on: i) greenhouse gas emissions (kg CO₂e), ii) water use (litres), iii) biodiversity loss (species lost x 10⁻¹⁴) and iv) eutrophication potential (gPO₄³⁻e), each per 100g of product. These analyses were conducted using the absolute values of indicators (rather than percentiles as in the EIS), logged to improve model fit (the indicators were highly skewed, with the majority of products having low scores on each indicator, while a few had particularly high scores). An exploratory secondary outcome examined the total environmental impact of shopping baskets, based on weighting each of the four environmental indicators equally.

Second, we explored differences in the nutritional composition of the shopping basket, as healthier foods may be more sustainable [24], including total energy (kcal), energy density (kcal/100g), salt (g/100g), and total carbohydrate, fibre, fat, saturated fat, and sugar, as % energy. We expressed these nutrients as % total energy to place the focus on the nutritional composition of the foods selected and not the absolute quantity of food purchased.

Finally, we examined differences in the overall spend on the shopping basket, expressed as £/100g.

Sample size

To determine the sample size for Study 1, we used standard deviation values from a pilot study with 90 people. Study 1 was powered at 90% to detect an absolute difference of 6% (SD1 = 18.9%, SD2 = 22.5%) in the total EIS between each intervention group and control. Based on our calculation, with a two-sided $\alpha = 0.05$ and allowing for a 15% non-compliance and attrition rate, we required a sample size of $n = 283$ per group (total $N = 1,132$). Study 1 was not powered to examine differences between intervention groups.

Study 2 was powered at 90% to detect an absolute difference of 6% (SD1 = 18.9%, SD2 = 23.8%) in the total EIS between each intervention group and control, as well as 4% difference (SD1 = 23.1%, SD2 = 23.8%) between intervention groups. We used values from the two trial arms with the largest standard deviations in the results of Study 1 which gave a sample size of $n = 400$ for the control group and $n = 1,000$ for each intervention group (total $N = 4,400$) with a two-sided $\alpha = 0.0125$ to allow for multiple comparisons between the four intervention groups using the Holm-Bonferroni method of adjustment [25]. In order to allow for a 15% non-compliance and attrition rate, we planned to recruit 5060 participants in total. In both studies, we examined the differences across shopping baskets between each intervention group and control on the primary and secondary outcomes. For Study 2, we also examined differences in effectiveness between intervention groups.

Sample size calculations were based on the pilot study method for calculating environmental impact scores (taking percentiles of scores across the sample)—this was discontinued for the main studies, due to concerns relating to this potentially being influenced by sample characteristics or the impacts of included study conditions. The rescaled outcome measures have smaller absolute differences, but correspondingly smaller variance, so are not expected to impact study power (and sensitivity analyses using this alternative show similar results).

Analysis

The primary aim of each study was to estimate the effect on the EIS when products were presented with environmental impact labels compared to control (no labels). In addition, in Study 2 we pre-specified two comparisons in label effectiveness between groups: i) A-E label vs Globe label and ii) Better label vs Worse label.

All participant data were screened by two independent researchers to determine eligibility for inclusion in the analysis. This involved meeting a minimum threshold (to allow calculation of the primary outcome), namely buying product(s) from at least 5 out of 10 categories on the shopping list. This acted both as a quality control check, and helped ensure comparability between participants. Beyond this criterion, an intention-to-treat approach was taken whereby all participants were entered into analyses (e.g. if participants bought more than the 10 requested items). An exploratory sensitivity analysis was conducted on just those participants who purchased 10 items.

In each study, we used linear regression to estimate the effectiveness of the labels compared to control. Participant characteristics were included in an adjusted linear regression model for each study, to explore associations between participant characteristics and the EIS. In Study 1 age and gender were included as factors in the adjusted model. In Study 2, age, gender, education, income, meat reduction, meat knowledge, meat consumption, and baseline hunger and fullness were included as factors in the model. Meat consumption was coded into a range of 1–4 by tallying participants' total meat and fish consumption on the meat frequency

questionnaire and splitting it into quartiles (see [S4 File](#) for survey questions and coding). Linear regression was used to explore the effects on individual environmental indicator values, the nutrient composition and spend on the shopping basket between conditions.

To determine whether label effectiveness varied due to participant characteristics, we ran separate linear regression models including interaction terms between each participant characteristic variable and intervention condition in exploratory analyses. Statistical analyses were conducted in STATA (Stata Statistical Software: Release 14. College Station, TX: StataCorp LP). The statistician was blinded to group allocation.

Results

Participant characteristics

In Study 1, participants ($N = 1,051$) were on average 38 years old ($SD = 12.7$ years), 59.5% were female, and 68.8% had shopped online for groceries in the last year. Participants selected a mean of 10.7 ($SD = 4.2$) products. In Study 2, participants ($N = 4979$) were on average 35 years old ($SD = 13.1$ years), 59.1% were female, and 68.9% had shopped online for groceries in the last year. Participants selected a mean of 11.4 products ($SD = 4.3$; [Table 1](#)). See [S5 File](#) for CONSORT Flow Diagrams.

Primary outcome: Effects of ecolabels on sustainable purchasing

In Study 1, there was a significant reduction in the EIS compared with control (mean EIS = 61.9 (62nd percentile) for all ecolabels: Petal label (mean difference = -3.9 percentiles, 95%CI: -5.3 to -2.6, $p < 0.001$), the A-E label (mean difference = -3.9 percentiles, 95%CI: -5.2 to -2.5, $p < 0.001$), and Combined label (mean difference = -3.2 percentiles, 95%CI: -4.5 to -1.9, $p < 0.001$) ([S1 Table](#) Model 1, [Fig 2A](#)). Exploratory analyses examining total environmental impact of shopping baskets also found significant reductions for each label ([S2B Table](#)). Moreover, because the change in the percentile score may not be indicative of the absolute change in environmental impact, the change in impacts for each of the four environmental indicators was also investigated ([Table 2](#)). The presence of an ecolabel consistently decreased the absolute impact for every environmental indicator: across conditions, there were significant reductions for greenhouse gas emissions (range: -13.9 to -14.8%), biodiversity loss (range: -12.2 to -15.6%), eutrophication potential (-11.3% to -13.9%), and water use (-18.9 to -25.9%).

In Study 2, there was a significant reduction in the EIS compared with control (mean EIS = 60.0) for the A-E label (mean difference = -2.3 percentiles, 95%CI: -3.0 to -1.5, $p < 0.001$), the Globe label (mean difference = -3.2 percentiles, 95%CI: -3.9 to -2.4, $p < 0.001$), and 'Worse' label (mean difference = -3.2 percentiles, 95%CI: -3.9 to -2.5, $p < 0.001$) ([S3 Table](#) Model 1; [S5 Table](#) for summary of covariates). There was no evidence of a difference in the EIS compared to control for the 'Better' label (mean difference = -0.5 percentiles, 95%CI: -1.3 to 0.2, $p = 0.143$) ([Fig 2B](#)). A similar pattern of results was found for total basket environmental impact, with the exception that the coefficient for the A-E label sat at the threshold for significance ($p = 0.05$; [S4B Table](#)). In the pre-specified intervention comparisons, the Globe label was more effective than the A-E label (mean difference = -0.9 percentiles, 95%CI: -1.4 to -0.4, $p < 0.001$) and the 'Worse' label was more effective than the 'Better' label (mean difference = -2.7 percentiles, 95%CI: -3.2 to -2.1, $p < 0.001$). Other exploratory comparisons are shown in [S4D Table](#).

In terms of absolute changes in impact on the environment, reductions were seen in each of the four environmental indicators compared to control for the Globe labels (range -8.6% to -15.6%) and 'Worse' labels (range -7.7% to -14.8%). The A-E labels significantly reduced impacts on the biodiversity loss indicator (-8.6%), with no evidence of significant reductions

Table 1. Baseline characteristics of the Study 1 and Study 2 participants.

	Study 1					Study 2					
	Control	Petal label	A-E label	Combined labels	Total	Control	A-E label	Globe label	Better label	Worse label	Total
N	263	262	265	261	1051	448	1138	1122	1129	1142	4979
Age, years, mean + SD	38.1 + 12.6	37.6 + 12.8	38.5 + 13.0	37.8 + 12.6	38.0 + 12.7	34.3 + 12.5	35.5 + 13.2	34.8 + 13.3	34.9 + 13.2	35.0 + 13.0	35.0 + 13.1
Age category, n (%)											
18–20 years	17 (6.5)	12 (4.5)	14 (5.3)	14 (5.4)	57 (5.4)	48 (10.7)	124 (10.9)	142 (12.7)	126 (11.2)	120 (10.5)	560 (11.3)
21–40 years	144 (54.8)	148 (56.5)	146 (55.1)	149 (57.1)	587 (55.9)	278 (62.1)	641 (56.3)	634 (56.5)	666 (59.0)	692 (60.6)	2911 (58.5)
41–60 years	94 (35.7)	84 (32.1)	87 (32.8)	80 (30.7)	345 (32.8)	100 (22.4)	295 (25.9)	275 (24.5)	263 (23.3)	259 (22.7)	1192 (23.9)
61+ years	8 (3.0)	18 (6.9)	18 (6.8)	18 (6.9)	62 (5.9)	22 (4.7)	78 (6.9)	71 (6.3)	74 (6.6)	71 (6.2)	316 (6.4)
Gender, % female	60.8	63.7	56.3	57.4	59.5	59.1	59.7	60.4	57.1	59.0	59.1
Household size, mean + SD	2.9 + 1.4	2.9 + 1.3	3.1 + 3.3	2.9 + 1.4	2.9 + 2.0	3.0 + 1.3	3.0 + 1.4	3.1 + 1.4	3.0 + 1.3	3.0 + 1.3	3.00 + 1.34
Items purchased, mean + SD	10.6 + 3.6	10.3 + 1.4	11.0 + 4.3	11.1 + 6.1	10.7 + 4.2	11.4 + 5.1	11.7 + 4.9	11.4 + 3.7	11.4 + 3.9	11.1 + 2.1	11.4 + 4.3
Online shopping, n (%)											
Never or not in last year	75 (28.5)	92 (35.5)	77 (29.3)	81 (31.4)	325 (31.2)	134 (30)	370 (33.0)	342 (30.8)	335 (30.0)	353 (31.3)	1534 (31.1)
1–3 times in last year	68 (25.9)	66 (25.5)	61 (23.2)	60 (23.3)	255 (24.5)	115 (25.7)	261 (23.3)	279 (25.1)	278 (24.9)	269 (23.8)	1202 (24.4)
4–11 times in last year	65 (24.7)	52 (20.1)	65 (24.7)	66 (25.6)	248 (23.8)	83 (18.6)	210 (18.7)	192 (17.3)	200 (17.9)	200 (17.7)	885 (18.0)
1–3 times per month	30 (11.4)	28 (10.8)	37 (14.1)	37 (14.3)	132 (12.7)	78 (17.4)	170 (15.2)	167 (15.0)	177 (15.9)	187 (16.6)	779 (15.8)
Once per week or more	25 (9.5)	21 (8.1)	23 (8.8)	14 (5.4)	83 (8.0)	37 (8.3)	111 (9.9)	131 (11.8)	127 (11.4)	120 (10.6)	526 (10.7)
Education, n (%)											
None	-	-	-	-	-	1 (0.2)	6 (0.5)	9 (0.8)	7 (0.6)	11 (1.0)	34 (0.7)
Secondary	-	-	-	-	-	196 (43.8)	455 (40.6)	456 (41.1)	474 (42.5)	434 (38.5)	2015 (41.1)
Higher	-	-	-	-	-	247 (55.3)	655 (58.4)	640 (57.7)	626 (56.1)	678 (60.2)	2846 (58.1)
Prefer not to say	-	-	-	-	-	3 (0.7)	6 (0.5)	5 (0.5)	8 (0.7)	4 (0.4)	26 (0.5)
Income, n (%)											
Less than £15k	-	-	-	-	-	132 (29.5)	352 (31.3)	357 (32.1)	355 (31.8)	380 (33.7)	1576 (32.0)
£15–24,999	-	-	-	-	-	118 (26.4)	280 (25.0)	263 (23.7)	284 (25.4)	263 (23.3)	1208 (24.5)
£25–39,999	-	-	-	-	-	115 (25.7)	266 (23.7)	255 (23.0)	278 (24.9)	271 (24.0)	1185 (24.1)
£40–75,000	-	-	-	-	-	51 (11.4)	139 (12.4)	155 (14.0)	120 (10.7)	129 (11.4)	595 (12.1)
Over £75k	-	-	-	-	-	9 (2.0)	30 (2.7)	27 (2.4)	28 (2.5)	31 (2.8)	125 (2.5)
Prefer not to say	-	-	-	-	-	22 (4.9)	55 (4.9)	53 (4.8)	52 (4.7)	55 (4.9)	237 (4.8)

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for the other indicators (range -1.0% to -3.9%). The 'Better' labels significantly reduced impacts on the biodiversity loss indicator (-11.3%) but significantly increased values on the water use indicator (8.3%) (Table 3).

A sensitivity analysis examining effects in those who purchased 10 items, as asked on the shopping list, showed similar patterns of results for both studies (S2B and S4B Tables).

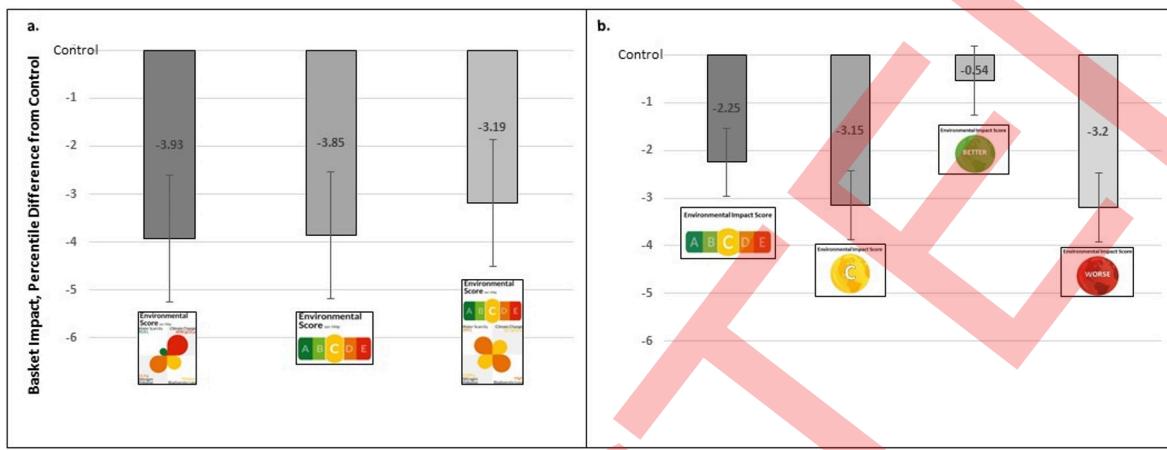


Fig 2. Difference in environmental impact scores. EIS (in percentiles), with 95% CIs, compared to Control (marked as X = 0) in Study 1 (a) and Study 2 (b).

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Secondary outcomes: Effects of ecolabels on the spend and nutrient composition of the basket

Across both studies, there were small (between 2p-4p /100g) but statistically significant differences in the spend on the shopping basket for three out of seven label conditions compared to control: the Petal label resulted in a more expensive basket and the Globe and Worse labels resulted in slightly cheaper baskets (Table 4).

There were occasional small and inconsistent effects on the nutrient content of baskets (Table 4). In Study 1, there were no differences between any of the label conditions and control in the total energy, sugar, fibre, protein, or salt content of the shopping basket. Only the A-E label condition had baskets with lower fat and saturated fat content in Study 1. However, in Study 2, the A-E label condition had baskets with higher fat and saturated fat content, and lower carbohydrate and sugar content. The Globe and Worse labels had mixed effects on nutrient content. The Globe significantly reduced the total energy (kcal) and salt content of the basket, but also had lower fibre content. Similarly, the Worse label had lower energy, fat, and saturated fat, but lower fibre and higher carbohydrate content, compared to control. The Better label had several positive effects on nutrients purchased, reducing the energy, saturated fat, sugar and salt content.

Table 2. Comparison of the individual environmental impact indicators between trial groups in Study 1.

n	Study 1						
	Control	Petal vs Control		A-E vs Control		Combined vs Control	
		Mean (95% CIs)	Coeff. (95% CI)	% Change	Coeff. (95% CI)	% Change	Coeff. (95% CI)
Greenhouse gas emissions	263	262			265		261
Mean (95% CIs)	0.49 (0.4, 0.51)	-0.16 (-0.23, -0.09)**	-14.8%	-0.16 (-0.23, -0.10)**	-14.8%	-0.15 (-0.22, -0.08)**	-13.9%
Biodiversity loss	12.1 (11.6, 12.7)	-0.16 (-0.23, -0.08)**	-14.8%	-0.17 (-0.24, -0.09)**	-15.6%	-0.13 (-0.21, -0.05)*	-12.2%
eutrophication potential	2.0 (1.9, 2.1)	-0.15 (-0.22, -0.08)**	-13.9%	-0.15 (-0.22, -0.08)**	-13.9%	-0.12 (-0.19, -0.05)*	-11.3%
Water use	2027.9 (1919.8, 2142.)	-0.27 (-0.36, -0.18)**	-23.7%	-0.30 (-0.39, -0.21)**	-25.9%	-0.21 (-0.30, -0.12)**	-18.9%

Note. Values are geometric means in column 1 and model coefficients with dependent variables being the natural logs of individual environmental indicators (95% CIs) in the columns 2, 4, and 6. %Change is calculated based on the exponentiated coefficients for individual environmental indicator scores

* $p < .05$

** $p < = 0.001$

<https://doi.org/10.1371/journal.pone.0272800.t002>

Table 3. Comparison of the individual environmental impact indicators between intervention groups and control in Study 2.

n	Study 2							
	Control		A-E vs Control		Globe vs Control		Better vs Control	
	448	1138	1122	1129	1142			
	Mean (95% CIs)	Coefficient (95% CI)	% Change	Coefficient (95% CI)	% Change	Coefficient (95% CI)	% Change	Coefficient (95% CI)
Greenhouse gas emissions	0.45 (0.43, 0.46)	-0.01 (-0.05, 0.02)	-1.0%	-0.09 (-0.13, -0.05)**	-8.6%	0.02 (-0.02, 0.06)	+2.0%	-0.10 (-0.17, -0.06)**
Biodiversity loss	11.2 (10.8, 11.6)	-0.09 (-0.13, -0.04)**	-8.6%	-0.17 (-0.22, -0.12)**	-15.6%	-0.12 (-0.17, -0.07)**	-11.3%	-0.08 (-0.13, -0.03)**
Eutrophication potential	1.9 (1.8, 1.9)	-0.03 (-0.07, 0.01)	-3.0%	-0.09 (-0.14, -0.05)**	-8.6%	0.00 (-0.04, 0.04)	0%	-0.10 (-0.14, -0.06)**
Water use	1729.6 (1661.8, 1800.0)	-0.04 (-0.09, 0.01)	-3.9%	-0.15 (-0.20, -0.10)**	-13.9%	0.08 (0.02, 0.13)*	+8.3%	-0.16 (-0.22, -0.11)**

Note. Values are geometric means in column 1 and model coefficients with dependent variables being the natural logs of individual environmental indicators (95% CIs) in the columns 2, 4, 6 and 8.

%Change is calculated based on the exponentiated coefficients for individual environmental indicator scores.

* $p < 0.01$

** $p < 0.001$

<https://doi.org/10.1371/journal.pone.0272800.t003>

Exploratory analyses

The adjusted linear regression models for each study showed that the EIS values increased with age ([S1 and S3 Tables Model 2](#)). In Study 1, there was no evidence of an effect of gender

Table 4. Comparison of spend and nutrient composition of the shopping basket between trial groups.

n	Study 1				Study 2				
	Control	Petal label vs Control	A-E label vs Control	Combined vs Control	Control	A-E label vs Control	Globe label vs Control	Better label vs Control	Worse label vs Control
263	262	265	261	448	1138	1122	1129	1142	
Spend, £/100 g	0.52 ± 0.14	0.02 (0.00, 0.05)*	-0.01 (-0.03, 0.01)	0.00 (-0.02, 0.02)	0.51 ± 0.14	-0.01 (-0.02, 0.00)	-0.04 (-0.05, -0.02)**	0.00 (-0.01, 0.02)	-0.03 (-0.04, -0.01)**
Energy, kcal/g	1.90 ± 0.40	0.04 (-0.03, 0.11)	0.01 (-0.05, 0.09)	0.04 (-0.03, 0.10)	1.72 ± 0.37	0.00 (-0.04, 0.03)	-0.09 (-0.13, -0.05)**	-0.10 (-0.14, -0.07)**	-0.09 (-0.13, -0.05)**
Fat, %energy	44.2 ± 8.1	-1.4 (-2.8, 0.1)	-1.6 (-3.1, -0.2)*	-0.8 (-2.3, 0.7)	45.3 ± 7.9	1.72 (0.86, 2.59)**	0.51 (-0.37, 1.38)	-0.31 (-1.18, 0.56)	-1.28 (-2.15, -0.41)*
Saturated fat, % energy	18.3 ± 4.3	-0.7 (-1.4, 0.1)	-0.8 (-1.5, -0.3)*	-0.4 (-1.1, 0.4)	18.6 ± 4.0	0.83 (0.38, 1.28)**	0.12 (-0.32, 0.57)	-0.47 (-0.92, -0.02)*	-0.56 (-1.00, -0.11)*
Carbohydrate % energy	34.3 ± 9.8	1.7 (0.0, 3.5)	1.7 (-0.1, 3.5)	1.1 (-0.7, 2.9)	34.3 ± 9.4	-1.75 (-2.73, -0.77)**	-0.20 (-1.18, 0.78)	0.47 (-0.51, 1.45)	1.68 (0.71, 2.66)**
Sugar, %energy	10.4 ± 3.8	-0.4 (-1.0, 0.2)	-0.4 (-1.0, 0.3)	-0.2 (-0.9, 0.4)	12.3 ± 4.0	-0.72 (-1.14, -0.30)**	0.09 (-0.33, 0.51)	-0.51 (-0.93, -0.09)*	-0.33 (-0.75, 0.09)
Protein, %energy	19.8 ± 3.9	-0.5 (-1.2, 0.2)	-0.2 (-0.9, 0.5)	-0.3 (-1.0, 0.4)	21.2 ± 4.8	0.00 (-0.50, 0.50)	-0.36 (-0.86, 0.14)	-0.19 (-0.69, 0.31)	-0.45 (-0.95, 0.05)
Fibre, g/100g	1.11 ± 0.44	0.04 (-0.03, 0.12)	0.02 (-0.06, 0.09)	0.04 (-0.03, 0.11)	1.44 ± 0.49	-0.05 (-0.10, 0.01)	-0.11 (-0.16, -0.06)**	0.00 (-0.06, 0.06)	-0.09 (-0.14, -0.03)*
Salt, g/100g	0.54 ± 0.86	0.01 (-0.12, 0.13)	-0.07 (-0.20, 0.05)	-0.08 (-0.20, 0.05)	0.51 ± 0.52	-0.02 (-0.06, 0.02)	-0.07 (-0.11, -0.03)**	-0.06 (-0.10, -0.02)*	-0.03 (-0.07, 0.01)

Note. Values are means ± SDs in columns 1 and 5 and mean differences (95% CIs) in the other seven columns.

* $p < .05$

** $p = < .001$

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on the EIS, but in Study 2 women had a significantly higher EIS than men. Participants who reported higher meat consumption had EIS that were higher than those of individuals who reported eating less meat. Lower levels of knowledge of the effect of meat on the environment and lower intention to reduce meat consumption were also associated with a higher EIS.

Interaction effects suggested the Petal and Combined labels may be more effective for younger age groups, whereas there was no evidence of differential impact of A-E labels by age in Study 1 or for any of the labels tested in Study 2 (**S1 and S3 Tables** Model 4). There were no significant interactions between the intervention and gender, nor by participant education, income and hunger in Study 2 (**S3 Table** Models 3, 5, 6 and 10).

In Study 2 there were significant interaction effects between intervention condition and meat knowledge, meat reduction, and meat consumption (**S3 Table** Models 7, 8, and 9). Without labels (in the control condition), those who believed eating meat was beneficial to the environment had lower EIS than those who believed it was harmful, but ecolabelling reversed this pattern as the EIS scores of those who believed eating meat was beneficial were changed less by the ecolabels. There was no evidence of any differences by EIS in the control group depending on participants' meat reduction intentions but, when environmental impact labels were displayed, those who had already reduced their meat consumption had lower EIS compared to those who reported wanting to increase meat consumption (and also compared to those who had no intentions to change or intended to reduce consumption for A-E labels). There was no evidence of a difference in EIS by reported meat consumption when no labels were present, but intentions to increase meat consumption were associated with higher EIS in the Globe and Worse label conditions.

Discussion

Meeting global climate targets will require a rapid reduction in diet-related environmental impacts. These proof-of-principle experiments show that five of the six environmental impact labels tested were effective at encouraging the selection of products with lower environmental impact scores across four environmental indicators (i.e. greenhouse gas emissions, water use, land use related biodiversity loss and eutrophication potential). In Study 1, all labels resulted in reductions in impacts across all indicators. In Study 2, the Globe, and Worse labels also reduced impacts across all indicators, while A-E and Better labels reduced biodiversity loss.

Previous evidence on the effect of demographic characteristics on the environmental impact of food purchases is inconsistent, with many studies finding no association [4]. Of particular concern are any interactions by measures of socioeconomic status. Our large sample sizes allowed for the detection of small effects, but we found no evidence of any interaction between education or income and label effectiveness. This provides some reassurance that environmental impact labelling is not expected to exacerbate inequalities.

Policy implications

These studies suggest that policies introducing ecolabels could be effective at changing consumer behaviour to increase the sustainability of food purchases, and provide insights into the types of ecolabels that may be most effective.

Many of the ecolabels found in grocery stores today (e.g. Rainforest Alliance Certified, Fair Trade) rely on highlighting a small proportion of products that meet certain criteria or regulations (albeit not necessarily translating into lower environmental impact scores), which could function as a 'go' cue towards purchasing these products. In Study 2, the 'Better' label (intended as a 'go' cue) was not effective at promoting the selection of lower-impact products whereas the 'Worse' label (intended as a 'no-go' cue) reduced the selection of higher-impact

products leading to an overall lower EIS. This finding is in line with previous research on the effects of go/no-go cues on the consumption of palatable foods [26]. No-go signals may be more effective because they promote food devaluation and discourage the frequency of selection of these foods [27]. Alternatively, or in addition, the individual environmental indicators were each highly skewed: many products had low impact scores and a few had very high scores. This suggests that moving away from the worst impact products (e.g. switching from an 'E' ranked to a 'D' ranked product) is likely to be more effective than making changes to the 'better' end of the distribution (e.g. going from a 'B' to an 'A' ranked product). The differential effect of "better" and "worse" labels is an important finding since those ecolabels found in grocery stores that rely on the 'better' label effect may not be effective in changing consumer behaviour. This suggests that policies with regard to ecolabelling should ensure that labels are not only placed on products that are regarded as 'better' choices, but that consumers are informed about those products with the greatest environmental impact. However, in a real-world setting, producers and retailers may be reluctant to target a proportion of their products to label as suboptimal ('Worse') choices, even though the evidence suggests this would be a more powerful tool to change food selection. This research shows that ecolabelling across all products is effective, and this may be an acceptable compromise. This supports previous findings suggesting traffic light environmental impact labels were effective at increasing the sustainability of product selections [13].

All products carried an ecolabel in the A-E and Globe conditions, both of which were effective at reducing the environmental impact of purchases. Study 2 suggested the Globe label was more effective than the A-E label (both of which displayed the same A-E grade on the same set of food products). We speculate that the pictorial globe image, which was inspired by focus group feedback, may prompt a more emotional response or provide a more salient visual cue for environmental concerns. This is in line with research exploring the effectiveness of front-of-pack nutrition label designs which suggests that including pictorial icons on front-of-pack labels might help people process information faster [28].

The Petal label was the only label that displayed values for each environmental indicator separately, thus providing transparency and detailed environmental impact information about a product. This could have advantages in focusing industry change across a broader spectrum of environmental concerns, compared to labels focused on a single indicator—or to a lesser extent a composite whereby a change to one component could change the overall score. While this label was effective in Study 1, our focus groups reported that this format was confusing and we did not take it forward and compare its performance with other labels in Study 2. Interaction analyses suggested the Petal label may be more effective for younger adults, who selected lower environmental impact products, and may have higher motivation to seek more detailed information. The Petal label also was the only label to result in the selection of more expensive shopping baskets relative to control, though the effect size was small. Despite these potential limitations, further work is needed to identify ways to encourage both industry and consumer consideration of a range of environmental concerns.

While we focused on changes in consumer demand, environmental impact labels could also prompt transitions throughout food supply chains, for instance by producers competing to reduce the impacts of their production systems, retailers promoting more sustainable products through price promotions, product placement and in-store marketing, or processors reformulating products to avoid higher-impact ingredients. Providing product-specific environmental impact labels could be an important step to help us reach the target of creating food systems that are compatible with global environmental targets.

Strengths and limitations

The strengths of these studies include the RCT design, high completion rate, and blinded statistical analysis. The use of a large number of products (>20,000) that are present in real supermarkets and a bespoke virtual grocery store website encouraged an engaging online shopping experience. Moreover, consistency in study findings despite changes to the range and order of products between Studies 1 and 2 demonstrate the effectiveness of environmental impact labels in the face of such variations—which will occur in real-world contexts and which can also impact on selection (for example, the percentage of products with A or B labels selected by control groups was 35% in Study 1, vs. 18% in Study 2; [S6 Table](#)). Another strength of this research is that it allowed for comparisons in effectiveness between environmental impact label designs due to the large sample size recruited in Study 2. Limitations include the experimental nature of these studies. Since participants were shopping for hypothetical foods in an experimental supermarket and not exchanging real money or receiving food, there is the risk that they may have selected lower-impact foods because they were aware of the study aims (perhaps particularly given they were recruited through market research panels and may therefore be more aware of study design), though this effect is minimised for comparisons between labels. Indeed, while previous studies examining nutritional labelling using experimental supermarkets have suggested that the effect sizes in experimental studies may be larger than seen in real purchasing contexts, the pattern of results has been found to be relatively consistent between findings in these experiments and real purchases [29, 30]. The shopping list in each study comprised a limited number of categories of products, and will not reflect the range of ways in which people shop [31]. Future work could examine differences in selections without the use of a shopping list, and also include additional incentives to maximise the probability that items selected are those participants would purchase, such as informing participants they would receive some of the items selected [29, 30]. Moreover, we introduced additional variability in environmental impacts related to different producers of the same product: specifically, we randomly assigned a 25th percentile, 50th percentile, or 75th percentile impact to ingredients of a product. It was important to include such variability as it exists in the real world, but future work will seek to use possible correlates of environmental impact (such as country of origin; whether the food is organically produced; etc.) to introduce this variance to ensure greater accuracy. We also excluded vegetarians and vegans in this study, for whom the relative effectiveness of ecolabels may differ. Given these limitations, the size of effects of the environmental impact labels may differ in a real shopping context where a broader range of products are likely to be purchased and where there may be less variation in label values within certain food categories. However, there is no reason why this should affect the findings regarding the relative effectiveness of different labels.

The focus of this paper was on the label format and not the methodology underlying the label values (considered elsewhere [14]). There are a variety of means to normalise and weight different indicators in life cycle impact assessments, however, and there is ongoing discussion as to their merits [32]. Future work could determine which weighting across indicators might be most effective at promoting sustainable purchasing behaviour, as well as how this weighting might vary across national and regional contexts.

Conclusion

Providing product-specific environmental impact labels at point of choice during grocery shopping may be a promising intervention to promote the selection of more sustainable food products. There is a plethora of eco-labelling schemes on the market and detailed evaluation of their performance in real-world retail environments is needed to identify the label layouts that

most effectively promote sustainable purchasing behaviour. The current studies highlight the promise of using a single environmental impact score, collating information from multiple different environmental indicators, which is applied across all products. Rapid development of a single consistent and effective label format is likely to be important for consumer awareness and if these are to play an effective role alongside other measures targeting behaviour change at the population-level.

Supporting information

S1 File. Categories of food groups displayed on the supermarket platform.
(DOCX)

S2 File. Process of label development.
(DOCX)

S3 File. Woods experimental online supermarket platform welcome screen.
(DOCX)

S4 File. Post-test survey.
(DOCX)

S5 File. CONSORT flow diagram.
(DOC)

S1 Table. Linear regression models for Study 1.
(PDF)

S2 Table. A. Comparison of the mean environmental impact score between trial groups in Study 1; B. Exploratory analyses for Study 1.
(DOCX)

S3 Table. Linear regression models for Study 2.
(PDF)

S4 Table. A. Comparison of the mean environmental impact score between intervention groups and control in Study 2; B. Exploratory analyses for Study 2; C. Comparison of the total environmental impact score between intervention groups in Study 2; D. Comparison of the individual environmental indicators between intervention groups in Study 2.
(DOCX)

S5 Table. Exploratory variables included in the regression model for Study 2.
(DOCX)

S6 Table. Percentage (n) of purchased items falling into each environmental impact grade, and the mean (s.d.) score on each environmental indicator of purchased items by grade.
(DOCX)

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