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TOPICAL REVIEW

Effectiveness of behavioural interventions to reduce household energy demand: a scoping review

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Abstract

This paper provides a scoping review of behavioural interventions that target household energy demand. We evaluate 584 empirical papers that test the effectiveness of a behavioural intervention to change behaviour associated with household energy demand. The most studied behavioural tools are *providing timely feedback and reminders* and *making information intuitive and easy to access*, followed by (in order) *communicating a norm, reframing consequences, making behaviour observable, obtaining a commitment, setting proper defaults*, and *transitions and habit disruption*. The most studied demand-side behaviour is electricity use. There is high heterogeneity in effect sizes. We classified the target behaviours of each study as *avoid, shift*, or *improve* behaviours and find that *avoid* behaviours (in particular, reducing electricity usage) are the predominant focus of researchers. The effectiveness of interventions differs across *avoid, shift*, and *improve* responses and by the behavioural tool. Specifically, *shifting* behaviours are less effectively motivated than *avoiding* behaviours by using an *information* intervention but more effectively by using a *norm* intervention. We review the literature to provide further information about which behavioural tools are most effective for specific contexts. The effectiveness of most behavioural tools are augmented when they are used in the right combination with other tools. We recommend that researchers focus future work on high impact behaviours and the evaluation of synergistic combinations of behavioural interventions.

1. Introduction

Household energy use accounts for approximately two-thirds of global GHG emissions, directly or indirectly (Ivanova *et al* 2016), with residential buildings responsible for 60% of building emissions (IEA 2019). Thus, the potential for demand-side reduction to shrink household energy use is substantial (Haas *et al* 2015, Haberl *et al* 2017, Masson-Delmotte *et al* 2018, Ivanova *et al* 2020). This paper focuses on interventions to change behaviour at the household level, where the connection from intervention to target behaviour and energy savings is direct. We do not evaluate non-residential building emissions or behaviours that are predominantly outside the home (i.e. in the workplace or commercial buildings), as those energy-use decisions often involve mediating parties, additional stakeholders, or policy changes.

The present review aggregates and summarizes existing empirical data to evaluate the scope of this body of literature and highlight gaps and future directions in the study of behavioural interventions to reduce household energy demand. A new chapter on 'Demand, services, and social aspects of mitigation' in the Sixth Assessment Report of the Intergovernmental Panel on Climate Change's (IPCC) Working Group III on Mitigation describes demand-side mitigation strategies in the global effort to reduce GHG emissions while attaining well-being for all (Creutzig *et al* 2022). While not a panacea and best employed in synergistic coordination with economic, technological, and broader socio-cultural interventions, behavioural interventions targeted at individuals and households are an important demand-side lever (Creutzig *et al* 2018). To summarize current evidence of the effectiveness of behavioural interventions to reduce household GHG emissions for the IPCC's Sixth Assessment Report WGIII demand side chapter, we reviewed all empirical, meta-analytic, and review papers on the topic. The results expanded far beyond the space limitations in the IPCC chapter and are thus reported in this paper. This paper offers a scoping review of behavioural interventions to reduce household greenhouse gas emissions and an overarching synthesis of the themes, gaps, debates, and consensuses in the literature.

There have been other reviews and meta-analyses of some parts of this literature, but none are as broad as the review presented here (see citations noted by an * in the Reference List and throughout the paper). Much of the literature in this area focuses on developing and testing behavioural interventions for specific target behaviours. Few empirical papers compare the effectiveness of different interventions (i.e. McCalley and Midden 2002, Abrahamse *et al* 2007). More look at the effectiveness of a given intervention across contexts and domains (e.g. the effectiveness of setting choice defaults, Jachimowicz *et al* 2019*) or conduct a meta-analysis of a specific intervention (e.g. providing smart meters, Ehrhardt-Martinez and Donnelly 2010*; or providing informational feedback, Zangheri *et al* 2019*; or norm messages, Farrow *et al* 2017*). A few notable meta-analyses have tackled the onerous, yet important, task of comparing intervention effectiveness between tools (Delmas *et al* 2013, Nisa *et al* 2019*, Khanna *et al* 2021). One recent report centralizes empirical work on energy efficiency interventions to offer an evidence map (Berretta *et al* 2021). Our scoping review attempts to integrate across all existing reviews and relevant research to report on the effectiveness of behavioural interventions to reduce household energy demand across behavioural tools and contexts.

Behavioural interventions and their targets have been classified in different ways in the literature. Some taxonomies classify interventions by the tool that is used, e.g. directing attention, feedback, norms, or incentives (Abrahamse *et al* 2005*, Osbaldiston and Schott 2012*, Delmas *et al* 2013*, Yoeli *et al* 2017, Andor and Fels 2018*, Khanna *et al* 2021*). Others differentiate by the specific behaviour targeted by the intervention, e.g. reducing electricity use, meat consumption, or fuel economy (Abrahamse and Steg 2013*, Pettifor *et al* 2017*, Wynes *et al* 2018*). Yet other taxonomies focus on the technology associated with the target behaviour, e.g. cookstoves or energy efficient appliances (Nisa *et al* 2019)*.

Far fewer taxonomies categorize by the more abstract nature of the behaviour change that is targeted in the transition. This has been done in a few ways and may predict the success of the behavioural intervention and the stickiness of the change. In this review we classify the targeted behaviour changes as *avoid, shift*, or *improve* responses (ASI) (Hidalgo and Huizenga 2013). This classification was originally developed in the context of transportation services, where *avoid* strategies reduce energy demand by eliminating trips, *shift* strategies do so by moving to less carbon-energy demanding modes of transportation, and *improve* strategies improve the energy efficiency of existing modes (Creutzig *et al* 2016). In this review we generalize these definitions in the following way: a targeted behaviour change is classified as *avoid* if the target behaviour is reduced or limited in some way (e.g. running the dishwasher less frequently, turning off the lights), *shift* if the intervention substitutes a behaviour that uses less energy for another (e.g. take public transportation instead of driving to work, change from natural gas-generated electricity to solar electricity), and *improve* if a behaviour makes a service less energy intensive (e.g. buying a more energy efficient refrigerator, choosing an ecofriendly dishwasher setting).

Behaviour changes to reduce household GHG demand differ in the psychological and economic efforts needed to make and sustain change. The ASI framework can help organize those changes (Creutzig *et al* 2018). *Avoid* may be the most difficult type of response as it asks the decision maker to give up something (e.g. a longer shower or a comfortable house temperature); *shift* responses may be less difficult because the intervention offers a substitute for obtaining the desired goal (e.g. getting to work by bus rather than personal car); and *improve* responses may be least difficult because it asks for a change in technology that provides the same (or improved) benefits as before (e.g. using the more energy efficient setting on a washing machine) (Creutzig *et al* 2022). Financial costs of the targeted behaviour changes are also highly variable and this heterogeneity cuts across ASI categories and behavioural tools, from lowering the thermostat to installing solar panels.

Below, we first conduct a scoping review of behavioural interventions to reduce household greenhouse gas emissions. We then qualitatively review the literature to investigate of the overall effectiveness of interventions. Finally, we discuss the implications of this review for researchers and practitioners.

2. Methods

2.1. Inclusion criteria

The search engines used to identify papers were Web of Science, PsychINFO, and Google Scholar. In addition, existing meta-analyses and reviews were used to identify papers to be screened for inclusion. The full search string is reported here: [(*home* OR *household* OR *residential* OR *individual* OR *transp**) AND (*energy* OR *greenhouse gas* OR *electricity* OR *heating* OR *cooling* OR *drying* OR efficien*) AND (*demand* OR *reduc** OR *conservation* OR *decreas** OR *mitigat** OR *low** OR *limit** OR) AND (*intervention* OR *intervene* OR) OR (*field stud**) OR *random* OR (*control group*)]. The initial literature search was conducted in June–July 2020 and two subsequent suppletory searches were conducted in June 2021 and November 2021. Papers in this review were all published in or before November 2021. Papers were included in the review if they (a) contain a behavioural intervention, (b) are published in a peer reviewed journal, highly cited, or included in a previous meta-analysis (including unpublished studies), (c) are original, experimental work, and (d) the targeted behaviour change impacts household energy demand.

2.2. Coding

Papers that passed the screen were coded for the following characteristics: (a) the behavioural tool employed, using the eight categories identified by Yoeli *et al* (2017): *setting a proper default, reaching out during a transition, providing timely feedback and reminders, making information intuitive and easy to access, making behaviour observable and provide recognition, communicating a norm, reframing consequences in terms people care about, and obtaining a commitment*; (b) whether the study was conducted in a developed country, using the Human Development Index; (c) the energy demand behaviour that was targeted, with the following categories: buying carbon offsets, choice of energy source, electricity use, investment in energy efficiency, or choice in mode of transportation; (d) the targeted type of behavioural change (ASI); and (e) whether the intervention employed an economic incentive with the behavioural tool. Papers were counted for a given behavioural tool if at least one study in the paper used the tool as the primary intervention. Papers that studied the effect of multiple behavioural tools were coded and included in the count for each tool. To distinguish between types of behavioural tools, *information* interventions must provide some information that goes beyond what would fall into the *feedback* or *norm* categories (e.g. an energy saving tip is considered an *information* intervention, descriptive norm information is a *norm* intervention, and individual energy usage is a *feedback* intervention).

3. Results

3.1. Scope of the literature

Table 1 provides an overview of the 584 empirical papers included in the scoping review. The most studied behavioural interventions are *providing timely feedback and reminders* (258 papers) and *making information intuitive and easy to access* (246), followed by *communicating a norm* (158). *Choice architecture* interventions, probably because they have been identified as tools for behaviour change more recently (Johnson 2021), are the least studied: 29 papers look at *defaults* and 11 papers focus on *transitions and habit disruption*. Electricity use is the most studied target behaviour (439 papers), followed by investments in energy efficiency (94), choice in mode of transportation (41), choice of energy source (17), and buying carbon offsets (4). *Avoid* responses are examined in the most papers (415 papers), followed by *shift* (112) and *improve* (77) responses. 72 of the 584 papers included an economic incentive; the *choice architecture* interventions of *reframing consequences* (26%) and *setting proper defaults* (24%) are most frequently combined with an economic incentive.

Two 'heat' maps illustrate information patterns from table 1. Figure 1 shows the frequency with which the eight behavioural tools were used to affect either *avoid, shift*, or *improve* responses. The tools were not used to the same extent to affect all three types of behaviour change (X^2 (14, $N = 584$) = 226.15, $p < 0.0001$). To affect *avoid* responses, the tools most often used were *information, making behaviour observable, norms, reframing consequences*, and *defaults*, whereas the tools most used to affect *shift* and *improve* responses were *information, norms, reframing consequences*, and *defaults*.

Figure 2 shows the frequency with which behavioural tools have been used to target specific energy behaviours. The tools were not used to the same extent for all energy behaviours (X^2 (28, $N = 584$) = 264.95, $p < 0.0001$). Electricity use, the most studied behaviour, is most frequently addressed by *providing feedback, making information accessible*, and *communicating a norm*. The next most studied target behaviour, investment in energy efficiency, is most often addressed by *providing information, making behaviour observable, reframing consequences*, and *communicating a norm*. To influence mode of transportation, the most studied tool is *providing information*. Figure 2 also shows which combinations of tools and target behaviours have been studied least.

Figures 3(a) and (b) summarize information about the joint application of behavioural tools in the reviewed papers: 57% of papers examined one tool, 34% examined two tools, and 9% examined three or four tools (figure 3(a)). The most common pairs of tools were *feedback* and *information* (109 papers), *feedback* and *norms* (62 papers), *norms* and *information* (40 papers), and *feedback* and *commitment* (30 papers) (figure 3(b)).

3.2. Effectiveness of behavioural interventions

Behavioural interventions vary greatly in their effectiveness to reduce household GHG emissions. *Setting proper defaults* is one of the highest impact

Table 1. Counts of papers that experimentally tested the effectiveness of different behavioural tools to reduce household energy demand. Paper counts are broken down by: the behavioural intervention(s); the type of country in the sample; the targeted energy demand behaviour(s); the *avoid, shift*, or *improve* response type; and whether an economic incentive is also included in the treatment. In the energy demand behaviour column, the number of papers that targets each behaviour is provided in parentheses.

Behavioural tool	# of papers	# in developed countries	# in other countries	Energy demand behaviour	Avoid	Shift	Improve	Economic incentive
Set the proper defaults	29	28	1	Carbon offset program (3) Energy source (4) Electricity use (16) Investment in energy efficiency (8) Mode of transportation (2)	11	12	9	7
Reach out during transitions	11	10	1	Electricity use (4) Investment in energy efficiency (4) Mode of transportation (3)	1	3	7	1
Provide timely feedback & reminders	258	248	10	Electricity use (254) Mode of transportation (3)	244	6	7	32
Make information intuitive & easy to access	246	234	12	Energy source (3) Electricity use (201) Investment in energy efficiency (29) Mode of transportation (20)	197	38	24	32
Make behaviour observable & provide recognition	64	59	5	Energy source (5) Electricity use (25) Investment in energy efficiency (31) Mode of transportation (4)	27	28	5	7
Communicate a norm	158	151	7	Carbon offset program (1) Energy source (7) Electricity use (123) Investment in energy efficiency (17) Mode of transportation (12)	106	21	16	17
Reframe consequences in terms people care about	78	72	6	Carbon offset program (1) Energy source (5) Electricity use (50) Investment in energy efficiency (21) Mode of transportation (3)	41	18	19	20
Obtain a commitment	52	47	5	Energy source (1) Electricity use (47) Investment in energy efficiency (1) Mode of transportation (5)	45	4	4	10

Figure 1. The frequency of papers that used the specified behavioural tool (rows) to affect either *avoid, shift*, or *improve* responses (columns). Cell color indicates relative frequency (darker: more papers, lighter: fewer papers).

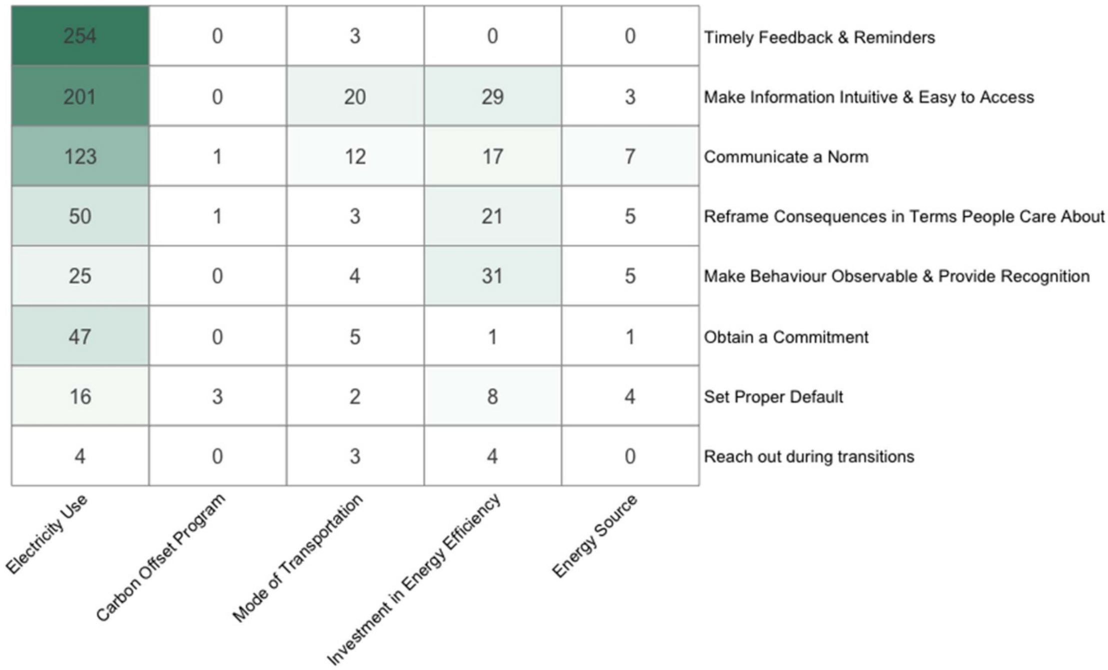

Figure 2. The frequency of papers that used the specified behavioural tool (rows) to target the specified energy demand behaviour (columns). Cell color indicates relative frequency (darker: more papers, lighter: fewer papers).

behavioural tools, meta-analyses find a medium[4] to large effect of defaults on behaviours that reduce energy demand (d = 0.35–0.75, Jachimowicz *et al* 2019*, Nisa *et al* 2019*). *Making behaviour observable and providing recognition* has a medium to large effect on energy savings (d = [0.79, 1.06]: Nisa *et al* 2019*, 6%–7% energy savings: Handgraaf *et al* 2013, Nemati and Penn 2020*, Winett *et al* 1979). *Obtaining a commitment* has a moderate but mixed effect, with significant energy reduction in only half of studies (Lokhorst *et al* 2013*, Andor and Fels 2018*, Iweka *et al* 2019*, Nisa *et al* 2019*). Nisa *et al* find a moderate average effect (d = 0.34, [0.11, 0.658]) and note that when people accept the goal or commitment that the experiment proposes, the effect size is larger (d = 0.48). The relatively small number of studies that examine the impact of *reaching out during transitions* report mixed results ranging from 3%

[4] Effect sizes that are reported at Cohen's d are discussed in 'small', 'medium', and 'large' terms according to Cohen's conventions (1988).

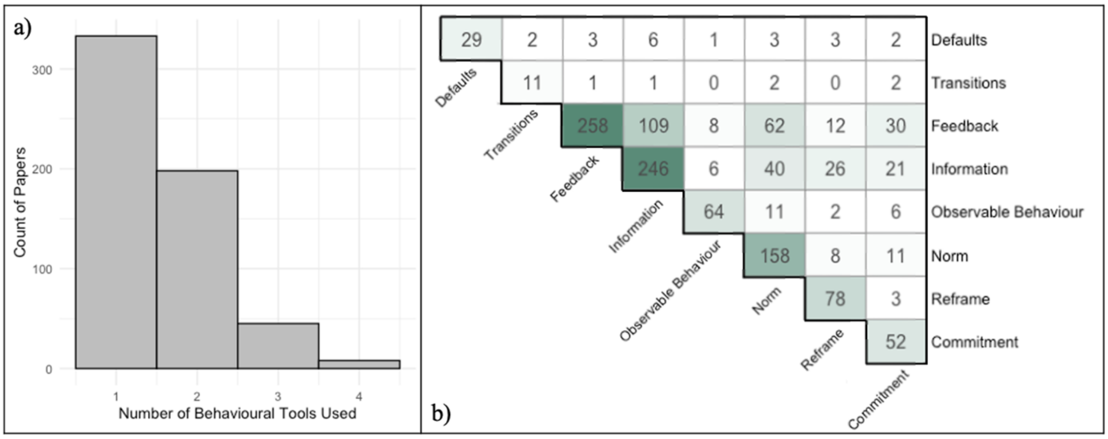

Figure 3. (a) Histogram of the number of behavioural tools used in each paper. (b) Frequency of papers that employed different pairs of behavioural tools. Cell color indicates relative frequency (darker: more papers, lighter: fewer papers).

to 13% energy savings (Mahapatra and Gustavsson 2008, Verplanken *et al* 2008, Jack and Smith 2016, Verplanken and Roy 2016). Meta-analyses of the myriad studies that study the effect of *communicating a norm* find a significant small to medium effect on household energy savings: average percentage savings range from 1.74% to 11.5% (Delmas *et al* 2013*, Andor and Fels 2018*, Iweka *et al* 2019*, Buckley 2020*) and effect sizes range from very small to small ($d = 0.08$ to 0.32) (Abrahamse and Steg 2013*, Bergquist *et al* 2019*, Nisa *et al* 2019*, Khanna *et al* 2021*). Meta-analyses of *timely feedback and reminders* interventions find effects that range from 1.9% to 7.7% reduction in household energy demand (Darby 2006*, Ehrhardt-Martinez and Donnelly 2010*, Delmas *et al* 2013*, Karlin *et al* 2015*, Nisa *et al* 2019*, Zangheri *et al* 2019*, Buckley 2019*, 2020*, Ahir and Chakraborty 2021*, Khanna *et al* 2021*). *Reframing consequences in terms people care about* has a significant small main effect ($d = 0.20$, [0, 0.42]; Khanna *et al* 2021*). *Making information intuitive and easy to access* has a small effect on household electricity use; meta-analyses find average energy savings between 1.8% and 7.4% and very small to small effect sizes ($d = 0.05$ to 0.30: Delmas *et al* 2013*, Buckley 2019*, Nisa *et al* 2019*, Nemati and Penn 2020*, Ahir and Chakraborty 2021*, Khanna *et al* 2021*). See the supplementary online materials (SOM) (available online at stacks.iop.org/ERL/17/063005/mmedia) for a more detailed review of the literature; table S1 offers a summary of the effectiveness of each behavioural tool reported in previous meta-analyses.

Across the interventions evaluated for this review, behavioural tools are more effective when they are specific, temporally close to the targeted behaviour, and have a social component. Specific interventions are those that make the intended behaviour change clear. Specific *feedback* interventions share usage data at the appliance-level for each consumer (Fischer 2008, Iweka *et al* 2019). Similarly, *information* interventions can be made more specific by offering energy savings tips that are tailored to the individual's prior behaviour (Buckley 2019*, Ahir and Chakraborty 2021*). Specific *norm* interventions include reference groups with whom the energy user is known to identify (Kurz *et al* 2005, Andor and Fels 2018*). Specific goal and *commitment* interventions enumerate the target quantify of energy savings (Abrahamse *et al* 2005*, Andor and Fels 2018*). (See SOM for further discussion of how to set energy conservation goals most effectively.)

Temporal closeness of intervention to target behaviour promotes behaviour change because it helps individuals more clearly understand the impact of their actions (Abrahamse *et al* 2005*, Darby 2006*). *Feedback* about energy consumption is more effective when it is frequent (Abrahamse *et al* 2005*, Fischer 2008, Ehrhardt-Martinez and Donnelly 2010*, Delmas *et al* 2013*, Karlin *et al* 2015*, Iweka *et al* 2019*, Zangheri *et al* 2019*, Buckley 2019*, 2020*, Khanna *et al* 2021*, McClelland and Cook1979, McClelland and Cook 1980) and direct (Darby 2006*, Ehrhardt-Martinez and Donnelly 2010*, Zangheri *et al* 2019*). Digital delivery is a promising strategy because it can be immediate and direct. This technology has been applied to monthly electric bills, through real-time digital in-home energy consumption displays, and as onboard digital fuel economy meters (Darby 2006*, Fischer 2008, Ehrhardt-Martinez and Donnelly 2010*, Faruqui *et al* 2010*, Zangheri *et al* 2019*). This type of intervention (e.g. digital home electricity monitors), especially when deployed at times of *transition*, is effective because it grabs one's attention (Karlin *et al* 2015*, Chatzigeorgiou and Andreou 2021*) and can disrupt habits to promote sustained change (Hermsen *et al* 2016*, Iweka *et al* 2019*).

Many interventions employ social elements in the form of *norms* or peer information, but with mixed results that suggest such tools should be deployed strategically. The Opower study, perhaps the prototypical study of the impact of social norms on household energy consumption, finds 2% reduction in total household electricity use (Allcott 2011). The decrease in energy consumption with repeated *norm feedback* is sustained even after the intervention ends (Ayres *et al* 2013, Allcott and Rogers 2014). However, the effectiveness of *norm* interventions, as compiled and analyzed by prior meta-analyses, is mixed, and indicates that social norm messages are not a panacea (Delmas *et al* 2013*, Karlin *et al* 2015*, Grilli and Curtis 2021*). Observing others' behaviour has a small but robust effect in the adoption of new technologies, specifically, electric vehicles and solar panels. Pettifor *et al* (2017)* find a small effect ($d = 0.20$–0.28) of *norm* interventions on selecting a more energy efficient car model. Social and, in particular, public commitments enhance goal-based interventions (Abrahamse and Steg 2013*, Grilli and Curtis 2021*). Iweka *et al*'s (2019)* comprehensive review shows that community-wide interventions result in 17% to 27% in energy savings.

Some social interventions, however, have unintended consequences—particularly when interventions are not appropriately tailored. An unintended consequence in the domain of household electricity use is observed when low electricity users are presented with a descriptive norm, learn that they outperform the norm, and thus increase their energy usage (Abrahamse *et al* 2005*, Schultz *et al* 2007, Allcott 2011, Allcott and Rogers 2014, Andor and Fels 2018*). This is especially prevalent in low income and low consumption households (Nielsen 1993, Bittle *et al* 1979, van Houwelingen and van Raaij 1989, Brandon and Lewis 1999, Hermsen *et al* 2016*). This effect can be ameliorated with the inclusion of an injunctive message that emphasizes the social desirability of energy savings, an example of the importance of combining interventions (Schultz *et al* 2007). *Making behaviour public or observable* is another way to avoid this type of negative reaction (Delmas and Lessem 2014). Other studies avoid this effect by offering comparative peer feedback about efficient neighbors (Ayres *et al* 2013*, Asensio and Delmas 2015*).

Many studies employ combinations of behavioural tools in their interventions, as shown in figures 3(a) and (b), and show that such combinations are effective. For example, *feedback* and *default* interventions are more effective when paired with motivation to reduce energy demand, either implicitly with *reframing* or explicitly with economic incentives (Fischer 2008). *Defaults* are more effective when they convey an endorsement of the defaulted option by the choice architect, in addition to making this option the reference point for the decision maker and thus inducing loss aversion (Jachimowicz *et al* 2019*). Additional synergistic combinations of interventions are discussed in the SOM.

4. Discussion

4.1. General discussion

A large body of literature investigates behavioural interventions to reduce household electricity use. This scoping review and the many meta-analyses and reviews that have come before show the interest in this topic. What is clear from our scoping review and prior reviews (Pettifor *et al* 2017*, Zangheri *et al* 2019*, Nemati and Penn 2020*, Sanguinetti *et al* 2020*), is that some interventions (i.e. *feedback, information*, and *social norms*) have been studied more than others (*transition* and *default* interventions). The technological and strategic innovations in these highly studied areas and the relatively low cost of their implementation have contributed to their popularity (i.e. digital in-home feedback displays, normative feedback and energy saving information on monthly electricity bills). However, we find that these interventions are often used on behaviour changes that require consistent, repeater behaviour change (i.e. reducing total household electricity).

Many high-impact *avoid* behaviours (e.g. reducing or eliminating meat consumption or air travel) would be considered very difficult by many Western consumers, and perhaps for that reason are rarely targeted for behavioural interventions. The most common example of *avoid* responses in our reviews was reduction in electricity use (table 1; figure 2). The nature of avoid change required consistent change, which can be psychologically fatiguing and people can lose interest or motivation. As discussed in the scoping review, more specific intervention targets have larger energy reductions. Previous meta-analyses for practitioners provide additional guidance on how best to develop and deploy *feedback, information*, and *norm* interventions to reduce electricity use (Šćepanović *et al* 2017*, Zangheri *et al* 2019*). Interventions that target general or ambiguous behaviours should be specific and temporally close.

There are also sizable gaps in the literature on high-impact emissions behaviours (Wynes *et al* 2018*). Most studies focus on low-impact behaviour changes, such has household electricity use (interventions have found an average 149 $kgCO_2e$/year/household reduction, 0.8% reduction of the average American's emissions). There is less work that studies personal vehicles; those interventions that have been studied measure a 571 $kgCO_2e$/year/driver reduction, 3.2% reduction of the average American's emissions (WRI 2014, Wynes *et al* 2018). Studies that examine energy decisions related to personal vehicles mostly examine only the effectiveness of economic incentives (Wynes *et al* 2018*). More work is needed to compare economic incentives to behavioural tools, either on their own or in combination.

Few studies focus on interventions that *shift* consumers to green electricity (see Wynes *et al* 2018* for a discussion of what has been studied), even though this is the household energy behaviour with the highest impact on GHG emissions that people can make (Wynes and Nicholas 2017).

To avoid the worst impacts of climate change, we must reduce global GHG emissions by much more than can be achieved with just behavioural change (Creutzig *et al* 2018). Behavioural science interventions work most effectively in conjunction with changing the physical infrastructure and political landscape, as a multiplier and facilitator of these interventions. New technologies—rooftop solar or electric vehicles, for example—are only effective if they are adopted and used by a lot of people. The technology and cost of production is undeniably important in reducing GHG emissions, but social influence, for example, can trigger peer effects that expedite adoption and lead to greater GHG reduction (Wolske *et al* 2020).

4.2. Combinations of interventions

Some combinations of behavioural interventions are more effective than a single behavioural tool (Osbaldiston and Schott 2012*, Iweka *et al* 2019*, Chatzigeorgiou and Andreou 2021*, Grilli and Curtis 2021*, Khanna *et al* 2021*). Our literature review finds congruent results, that specific combinations of behavioural tools augment the effect, for example *defaults* with *reframing*, *commitments* with *observable behaviour*, and *feedback* with energy saving *information* (SOM, section 2). See Khanna *et al* (2021)* for a rigorous meta-analysis of such combinations. They evaluate the incremental improvements that some combinations have over one of their components. *Feedback* and *reframe consequences* tools are present in many of the effective combinations. Economic incentives have the highest individual average effect, and they appear in the two most effective intervention combinations. Iweka *et al* (2019)* also find economic incentives, or rewards, to be an effective addition to a behavioural intervention, but the effect only lasts while the reward is being distributed.

Previous meta-analyses have found that interventions that employ a combination of behavioural tools are the most effective. Osbaldiston and Schott (2012)* offer one of the first meta-analyses to evaluate combinations of interventions; they find the following six combinations to be particularly effective: rewards and goals, instructions and goals, commitment and goals, prompts and making it easy, prompts and justifications, and dissonance and justifications. More recently, Grilli and Curtis (2021)* find that the most successful combined interventions include outreach and relationship-building. These interventions fuse *information* sharing with the social influence of teaching people in a group, they *make behaviour observable* by intervening on the whole community. Chatzigeorgiou and Andreou (2021)* emphasize the importance of clarity and specificity when designing *feedback* interventions, both to improve the effectiveness of interventions and to extract concrete measurements of effect from each type of intervention.

4.3. Developed countries vs. other countries

This scoping review shows that a large majority of research has been conducted in developed countries, and that there is a paucity of empirical work that investigated the effectiveness of behavioural change to reduce household GHG emissions in developing and pre-industrial countries. A few notable exceptions to this are the following studies of behaviour change in developing countries and emerging economies: (Xu *et al* 2015, Chen *et al* 2017, Mi *et al* 2019, 2020a, 2020b).

The field's focus on the developed world is reflected in the behaviours that are targeted for change, most of which are predicated on an unacknowledged set of parameters. Few studies consider households that are not in the affluent West, let alone homes without stable electricity or the financial means to invest in new appliances. There is some justification for focusing this work on countries that are responsible for the highest household GHG emissions—mitigation efforts should be placed at the source of emissions. However, this leaves a large portion of the world to which research insights gathered in developed countries are unlikely to transfer and where research does not exist to instruct policy makers on how to improve household behaviours. There is mixed to negative support for how well household energy interventions work when applied in different countries (Pettifor *et al* 2017*, Khanna *et al* 2021*).

Climate change mitigation research that has focused on developing countries has largely centered around the development of new technologies, for example cookstoves (Hanna *et al* 2016). However, without adequate adoption, technological improvements will not have a significant or lasting impact. Even a well-designed, affordable new product is not guaranteed to be adopted, and regional expertise and understanding is critical to developing solutions that people will use (Hanna *et al* 2016).

4.4. Avoid-shift-improve responses

Most work on the effectiveness of behavioural interventions for energy demand reduction has focuses on *avoid* responses, albeit in relatively easy energy contexts (like reducing household electricity consumption by a small percentage vs. foregoing flying), and relatively less work on *shifting* and *improving* responses (table 1; figure 1). Electric vehicles and rooftop solar panel adoption are the main behaviours that have been studied as *shifting* or *improving* behaviours. The focus on *avoiding* behaviour might, in part, explain the temporal decay that is observed in many papers. Many *avoid* behaviours (e.g. turning off lights or computers) require repeated action and sustained attention and have a low impact for each individual action, making the transition cognitively taxing for a relatively small and unsustained impact (Reeck *et al* 2022). Interventions that focus on habit change have been most successful for *avoiding* responses; these techniques have also been applied to *shifting* responses (Wynes *et al* 2018*).

Shift and *improve* responses have higher behavioural plasticity, the fraction of nonadopters who could be induced to change their behaviour (Dietz *et al* 2009). Improving behaviours, such as weatherization and fuel-efficient cars, have the highest potential impact, in terms of emission reduction, and highest behavioural plasticity. *Shifting* behaviours, such as driving behaviour and car-pooling, have high potential emission reductions and lower plasticity making them more promising targets for intervention studies.

4.5. Methodological discussion

Our scoping review provides extensive evidence of publication bias (Abrahamse and Steg 2013*, Delmas *et al* 2013*, McKerracher and Torriti 2013*, Karlin *et al* 2015*, Bergquist *et al* 2019*, Buckley 2019*, Nisa *et al* 2019*, Nemati and Penn 2020*, Khanna *et al* 2021*), which indicates that published effect sizes are likely to be too high. One way to ameliorate this bias is to reference grey literature and pilot projects in addition to published studied (see Buckley 2019* for a comparison of peer reviewed and grey literature studies). Meta-analyses have also found that sample size is negatively correlated with effect size and that random control trials have smaller effect sizes (Karlin *et al* 2015*, Buckley 2019*, Nisa *et al* 2019*, Nemati and Penn 2020*). There have already been notable improvements along these dimensions, with recent studies (2005 onward compared to the 1980s) using larger samples, control groups, and more random assignment (McKerracher and Torriti 2013*, Hermsen *et al* 2016*, Wynes *et al* 2018*, Buckley 2019*, Nemati and Penn 2020*). Additional methodological features that impact effect size are lab versus field studies, whether the outcome measure is self-reported or observed, and whether the outcome measure is an attitude, intention, or behaviour (Hermsen *et al* 2016*, Nisa *et al* 2019*). Observed outcome measures, in addition to self-reported measures, are important in avoiding the Hawthorne effect (Schwartz *et al* 2013, Hermsen *et al* 2016*). Future work should incorporate methodological best practices of large sample sizes, random assignment, control groups, and field applications. This suggests to practitioners that they should seek out meta-analyses, specifically those that correct for publication bias and review grey literature.

Too few studies examine the long-term impact of interventions. Meta-analyses indicate length of the intervention and measurement period impact overall effect size (Khanna *et al* 2021*). Most studies evaluate the effect of intervention at the end of its deployment, which is perhaps more descriptive of the transitional impact that the complete impact (Zangheri *et al* 2019*, Grilli and Curtis 2021*). Studies that do evaluate long-term and post-intervention impacts find that effect size decays over time (Allcott and Rogers 2012, Nemati and Penn 2020). The rebound effect, the unintended consequence of people increasing their energy consumption in response to an intervention, should be evaluated by measuring energy consumption for longer periods of time, especially after the intervention has been executed (Alvi *et al* 2018). There is some evidence to suggest some types of interventions become more effective over time, for example *choice architecture* interventions and energy audits (Iweka *et al* 2019*). Future research ought to routinely measure longer term impacts.

The behavioural interventions literature has focused on the aspects of household energy demand that are most easy to study. Future work should prioritize high impact behaviours, for example air travel or diet. These are behavioural changes that require *avoiding* behaviour change and are some of the most difficult to address.

Data availability statement

The data that support the findings of this study are openly available at the following URL/DOI: https://osf.io/h69bx/?view_only=2847e0b5b42b4aae9758a274c14f0cee. Data will be available from 1 January 2022.

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