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The question of energy reduction: The problem(s) with feedback

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HIGHLIGHTS

- We provide a comprehensive critique of feedback and in-home-displays (IHDs).
- We find limited evidence of the efficacy of feedback in reducing energy consumption.
- Problematically the success of IHDs depends entirely on user engagement.
- The unintended consequence of IHDs may undermine their energy reduction capabilities.
- We call for new IHDs to be developed and evaluated with user engagement in mind.

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ABSTRACT

With smart metering initiatives gaining increasing global popularity, the present paper seeks to challenge the increasingly entrenched view that providing householders with feedback about their energy usage, via an in-home-display, will lead them to substantially reduce their energy consumption. Specifically, we draw on existing quantitative and qualitative evidence to outline three key problems with feedback, namely: (a) the limited evidence of efficacy, (b) the need for user engagement, and (c) the potential for unintended consequences. We conclude by noting that, in their current form, existing in-home-displays may not induce the desired energy-reduction response anticipated by smart metering initiatives. Instead, if smart metering is to effectively reduce energy consumption there is a clear need to develop and test innovative new feedback devices that have been designed with user engagement in mind.

1. Introduction

Across Europe, the USA, Canada, New Zealand, and Australia, multibillion pound initiatives to install smart meters into residential homes are gathering momentum. For example, current UK government policy requires energy suppliers to install smart meters in every domestic property by 2020 (DECC, 2013a). The proposed smart meters will send accurate meter readings directly to energy providers and also allow consumers to monitor both their electricity and gas consumption using an associated in-home-display (IHD). One of the main justifications the UK government has given for the smart meter initiative is that IHDs will help “consumers have more control over their energy use and spending, while also helping meet environmental and security of supply objectives” (DECC, 2012; see also DECC, 2009).[1] Clearly implicit in this justification is the expectation that providing consumers with IHD-based feedback will equip them with the information they need to help reduce their overall energy consumption (see also, Darby, 2010; Strengers, 2013), shift it away from periods of peak demand, and/or respond flexibly to periods of “over” supply.

It seems to us that tremendous faith is being placed in the capabilities of feedback delivered through current IHDs to produce substantial energy reductions. Yet, we think such faith is misplaced and argue that there is considerable cause to question the plausibility of claims based on it. We have arrived at this viewpoint after conducting a qualitative analysis of consumers' self-reported experiences with

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[1] We note that there are other justifications too, for instance another benefit mentioned is the gradual implementation of time of use tariffs that could potentially help shift peak loads (DECC, 2013b). Whilst this might not reduce overall energy consumption, it may reduce the need to construct new generation facilities (ibid) or reinforce existing networks. However, in this paper we do not intend to provide a holistic evaluation of the smart meter initiative but rather to critically consider if feedback delivered via IHD constitutes an effective strategy for energy reduction.

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IHDs (Buchanan et al., 2014), which ultimately led us to identify substantial limitations that centred on the necessity of user engagement for effective outcomes. Moreover, in reviewing the available literature we also observed several additional feedback related problems that caused us to question whether current IHDs are really an appropriate tool for household energy reduction.

In the following viewpoint piece, we therefore aim to provide a comprehensive overview of the potential pitfalls of existing IHDs from a practical and applied perspective.[2] Notably, we do not seek to deny that feedback may have benefits, but rather we intend to encourage some healthy scepticism about the ability of *existing* IHDs to support substantial reduction in domestic energy consumption. In choosing to focus on identifying the problems associated with feedback, we provide an alternative perspective from the previous literature, which has largely concentrated on ascertaining the effectiveness of feedback and the conditions under which it may best work (e.g., Fischer, 2008).[3]

In this paper, we first review quantitative research that examines the efficacy of feedback in reducing energy consumption. We then draw primarily on qualitative evidence to outline the challenges that feedback faces from a user engagement perspective, before considering some unintended consequences that may undermine the capabilities of IHDs to reduce energy demand. We conclude by reflecting on the implications that these evidence threads have for future policy and research. In consequence, although feedback encompasses a variety of communication strategies distributed via different media (Fischer, 2008), our reading of the relevant UK policy documents (DECC, 2014) leads us to focus predominantly on feedback that is presented using an IHD that displays the kind of information about real-time, historical and cumulative consumption in both energy (kWh) and monetary (£) terms. In doing so we note that (over) concentration on these economic aspects appears central not only to the UK governments proposed plans but also to other global smart metering initiatives.

2. The efficacy of feedback: limited evidence

A multitude of empirical studies have examined the extent to which feedback can reduce energy consumption whether delivered via an IHD or other means. Results have varied and effect sizes have differed both within and between studies (Vine et al., 2013). While some studies have not found statistically significant effects (e.g., Alahmad et al., 2012; Allen and Janda, 2006; Scott, 2008), others have reported that energy savings range from 3% to 20% (e.g., Abrahamse et al., 2005; Darby, 2006; Ehrhardt-Martinez et al., 2010; Fischer, 2008; Harries et al., 2013). Such variation may be attributable to differences in study design as feedback has taken a variety of forms (e.g., marketing campaigns[4] vs. electronic communications) using diverse study groups (ranging from self-selected volunteers to random population samples). Indeed, a recent meta-analysis (Delmas et al., 2013) demonstrated that from a methodological perspective, less robust studies without controls (N[5]$=75$) yielded higher energy savings of 10% ($SD=12.1$, ranging from savings of 55% to increased consumption of 8%), whereas more robust studies that used either a control group and/or also took into consideration either household demographics and/or weather ($N=22$), yielded lower energy savings of 2% (SD: 1.05, ranging from savings of 5% to increased consumption of 5%).[6] Such findings underscore the importance of employing rigorous methodological designs to ensure that any energy savings are attributable to feedback rather than to self-selection bias and/or Hawthorne effects, whereby participants change their behaviour as a result of being involved in an experiment or study. For example, simply sending weekly postcards to remind residents of their participation in a domestic consumption study caused a 2.7% reduction in electricity use (Schwartz et al., 2013). To the best of our knowledge, existing studies have not used weekly reminders in their control conditions and people in the "no treatment" control conditions may therefore forget that they are even participating in a study. Consequently, it is unclear whether even robust studies with control and treatment group designs have disentangled Hawthorne and feedback effects. Yet without this distinction, the differences in consumption between the control and test condition may be overestimated. Moreover, without isolating the Hawthorne effect it is not possible to establish a deeper understanding of it within the domestic energy context. Yet, such knowledge could be used to derive the most effective aspects involved in the Hawthorne effect (e.g., increased interaction, social presentation concerns), so that they could be implemented in subsequent interventions to bolster the overall effectiveness of feedback.

In addition, researchers have also critiqued the short-term durations of existing feedback intervention studies (e.g., Delmas et al., 2013 note that 60% of studies had durations of just 3 months) and the use of multiple feedback strategies within a single treatment condition (Abrahamse et al., 2005; Delmas et al., 2013; Fischer, 2008). Evidently, such issues make it difficult to ascertain whether the effects of feedback persist in the long term and to pinpoint exactly which aspect of feedback was most effective or if it only worked because a combination of strategies were simultaneously utilized.

Perhaps most crucially for the smart meter roll-out programmes, few trials have assessed the contribution of real-time feedback to energy reductions despite the fact that such trials have the most relevance for identifying the energy savings obtained from IHD initiatives. For instance, only 1 (Alcott, 2011) out of the 22 "high quality" studies from Delmas et als'. (2013) meta-analysis examined the effect of real time feedback on energy consumption and even then the study focused on the impact of real time pricing rather than basic consumption information. Perhaps more relevant are findings from the Energy Demand Research Project (AECOM, 2011), a large scale trial involving over 60,000 households, that was conducted between 2007 and 2010 by the UK's 4 main energy suppliers with the aim of establishing the impact of various information based interventions. Interestingly, in the trials where households were *only* provided with a real-time display, just one out of four of the energy suppliers reported finding a significant reduction in consumers energy use. Curiously, these reductions only occurred for electricity and not gas consumption, which raises important (and as yet unaddressed) questions about why IHDs may differentially affect gas and electricity reduction. Moreover, the reduction was small at just 1% suggesting that IHDs (on their own) have a very small part to play in the 20% reduction in energy consumption demanded by the UK's energy strategy (DECC, 2013a).

To summarize, (i) there is a scarcity of research that can be classified as both relevant and robust, and (ii) the evidence that there is does not make a compelling case for the efficacy of

[2] While we draw on some theoretical insights from practice theory (e.g., Shove and Walker, 2014), affordance theory (Darby, 2010) and Fischer's theory of energy feedback (2008) this paper does not intend to provide an exhaustive review of each of these approaches and as such does not constitute a theoretical paper. Rather, we use these theoretical insights to identify the practical implications that may affect the capabilities of IHDs to reduce energy consumption.

[3] We note that both Pierce et al. (2010a) and Strengers (2013) have also critiqued various aspects of the feedback agenda.

[4] In this context "marketing campaigns" refers to large scale advertisements which are designed to raise awareness of efficient energy consumption.

[5] N refers to number of reviewed studies.

[6] Albeit significantly different from 0, $t(21)=9.04$, $p<.01$

feedback in general in reducing energy consumption. Given (i), in the following subsections we draw on the available evidence which is largely qualitative (and may not be classified as high quality according to statisticians) but nonetheless provides a valuable perspective that vividly demonstrates the complexities and problems involved with IHDs.

3. A user engagement perspective: why the “human factor” matters

In the previous section we considered whether “statistically speaking” feedback in general, and IHDs in particular, can substantially reduce energy consumption. Yet, absent from this section was the acknowledgement of a key variable vital to the success of IHDs-the “human factor”, which we define as the components and processes involved in consumer engagement with IHDs. The term is necessarily broad and involves consumer interest, motivation, comprehension, evaluation, reflection and personal characteristics. In adopting this term, we hope to highlight the undeniable fact that IHDs cannot reduce energy consumption by themselves, but that this depends on human interaction and action.

3.1. Disinterested consumers

Some degree of interest from end users is required either from the outset or after acquiring an IHD. Yet, ominously for the UK smart meter roll-out plans, a recent nationally representative UK survey revealed that 59% of bill-payers expressed no interest in having an IHD installed in their homes (DECC, 2013c). Likewise, the generation of interest following the acquisition of an IHD seems rare. Wallenborn et al. (2011) found that only households that were *already* interested or involved in energy savings were willing to use energy monitors and learn from them. Similarly, Pierce et al. (2010a, 2010b) found that even when households received free IHDs they did not use them. Specifically, 12 households were provided with IHDs in return for their prior participation in an energy related study. The IHDs were presented as a “bonus” in case households found them interesting or useful. Amazingly, none of the households used the IHDs, explaining that they “*didn't get around to it*” or were “*just too busy*”.

In cases where consumers' interest in the IHD does occur (either pre- or post-acquisition), it is uncertain whether such interest will persist in the longer term – along with any initial reductions in energy consumption. Currently, existing knowledge of this issue is limited, due to a scarcity of interventions examining the long-term effects of feedback (Abrahamse et al., 2005). Nonetheless, there is still some indication that consumers' engagement with IHDs may lessen over time (Ueno et al., 2006a; Van Dam et al., 2010). Specifically, Van Dam et al. (2010) found that initial savings in electricity consumption of 7.8% after 4 months were not sustained 15 months later, and Pereira et al. (2012) found that users started to pay less attention to feedback after 4 weeks, as demonstrated by a 60% decrease in interactions with the IHDs. Moreover, several qualitative studies have also observed that after an initial period of intrigue, people lose interest as the novelty of receiving feedback wears off. The IHDs stop offering new information and fade into the background of everyday life (e.g., Barreto et al., 2013; Hargreaves et al., 2013; Mountain, 2006; Ueno et al., 2006a, 2006b) – an effect sometimes referred to as “the fallback effect” (Wilhite and Ling, 1995). Indeed, as one consumer who had purchased an IHD reported, “*But once you're aware of the cost of a cup of tea etc. the novelty wears off! Shame you can't hire it for a month!*” (Buchanan et al., 2014). This loss of interest is also documented in a government survey which found that one in five people reported never looking at their IHD (DECC, 2013b). Given that the success of feedback depends on user engagement, this loss of interest is detrimental and may severely hamper the likelihood that IHDs will result in energy reductions that persist in the long term. As such, waning interest caused by initial novelty effects may be one of the biggest obstacles to the success of feedback based initiatives.

3.2. Problematic financial motivations

Notably, when there *is* interest in consumption information, it appears to stem primarily from financial motives with environmental motives featuring second, almost as an afterthought (Buchanan et al., 2014; Hargreaves et al., 2010). Making use of the predominance of “cost” as a motivation for changing behaviour is problematic for three reasons. First, changes in behaviour need to be reinforced by delivering rewards soon after the behaviours' occurrence. Yet in the UK, the majority of consumers pay for energy in arrears and/or via fixed monthly payments. This means that there is a substantial period of time elapsing between engaging in an energy reduction action and being rewarded for doing so. In addition, current estimates suggest that the savings obtained by implementing behavioural changes might be small. According to Ofgem (2013), the average British household pays £1342 in energy bills so, if energy reductions of 2% (Delmas et al., 2013) are achieved, then IHDs could result in savings of £2.23 per month. Such savings may not be considered worthwhile and may even undermine households' energy saving motivations, particularly where energy-using practises are valued by occupants and/or deeply embedded in daily routines. Second, framing feedback in terms of financial costs rather than CO_2 savings may reduce the likelihood of climate change becoming a salient issue, and thus may negate the opportunity for behavioural spillover (e.g., Maio et al., 2009; Spence et al., 2014) – an effect whereby users may expand their environmentally-friendly actions beyond the targeted behaviours (in this case reduced energy consumption) to include other environmental behaviours (e.g., recycling). Third, to further complicate matters, this emphasis on financial motivations makes the assumption that some form of “rational” cost benefit analysis *can* be carried out and that this type of decision making approach is part of daily life (Shove, 2010; Strengers, 2013). Yet, such an assumption is questionable given that consumers do not use energy for its own sake but rather it emerges as a by-product of everyday activities (Shove and Walker, 2014).

3.3. Comprehension issues

Despite assuming that occupants *are* motivated to reduce their consumption, they still face a “tricky cognitive problem” (Kidd and Williams, 2008) or a “formidable task” (Stern and Aronson, 1984, p. 83) – making sense of their consumption. It is presumably hoped that the provision of IHDs displaying real-time, historical, and cumulative consumption in both pounds and pence, and kWh (DECC, 2014) will improve consumers' understanding of energy consumption patterns. Yet, given that British consumers' understanding of their energy bills is already low (Darby, 2010), it is possible that the presentation of “meaningless” live numbers (Kidd and Williams, 2008) or cumulative information about daily or weekly consumption may only confuse them further, especially given that consumers currently receive their utility bills *after* consumption has occurred. Indeed, in achieving comprehension, consumers face several challenges. First, some IHDs use daily or weekly consumption to forecast monthly or yearly costs. This can lead to wildly erratic estimates (according to which appliances are in use at any given moment) that the end user may find hard to trust and difficult to act upon (Darby, 2010). In a similar vein, until the IHDs have collected sufficient data, unless users revisit previous bills they will be unable to evaluate whether their use is higher or lower than "normal" compared to similar seasons. Second, although money may be more meaningful to consumers than kWh (McKerracher and Torriti, 2012), the price of energy fluctuates (e.g., between 2010 and 2013 UK consumers saw an overall increase of 37%), which may lead to frustration when attempts to reduce yearly energy bills literally do not appear to pay off. Finally, and perhaps most importantly, householders still have to deduce which "changeable" aspects of their lifestyle contributes significantly to their consumption. Such confusion may be exacerbated by the fact that there are no plans (DECC, 2014) to present information in a disaggregated form (e.g., appliance level) to which consumers can relate their energy-using practices (see also Dennis et al., 1990). This is equivalent to trying to reduce expenditure on food without receiving an itemized grocery bill (Kempton and Layne, 1994). Yet, other "sense-making" details could be provided, such as energy use by space (e.g., specific rooms or areas), source categories (kitchen appliances, lights) or even specific sources (e.g., kettle, shower). Whilst the provision of such information may be within the scope of proposed third party "energy management services", for those who do not participate in such services, and so lack this detailed and disaggregated information, there is no alternative but to conduct mini investigations. These may consist of switching appliances on and off, while observing the IHD, in order to link cost, consumption, and behaviour (Buchanan et al., 2014; Hargreaves et al., 2013). Of course, while the real-time information provided by IHDs may help consumers to identify the impact of their practises on energy consumption, not everyone will have the inclination or expertise required to participate in such investigations. Indeed, it is clear that understanding IHDs is no easy task and interviewees in at least three qualitative studies have variously commented on comprehension issues stating, "*I haven't worked it out… I didn't really understand it.*" (Kidd and Williams, 2008), "*I don't understand anything at all about it*" (Van Dam et al., 2012) and "*She [my wife] doesn't understand it really*" (Hargreaves et al., 2010). Moreover, results from a recent government survey found that people with no formal qualifications were less likely than those with A-levels to report that their IHD had helped them to reduce their electricity bills (41% vs. 72%, DECC, 2013b). We might infer therefore, that comprehension involves certain numeracy skills and analytic competencies that not everyone may have, but that are seemingly needed if consumers are to unlock the potential energy reduction capacities of IHDs.

3.4. Evaluation processes: judging the numbers

Evaluation, the process during which moral, environmental, personal, or social costs and benefits are considered, is a key component in energy feedback (Fischer, 2008). Evaluation is considered crucial because it is an antecedent to any subsequent energy saving actions. Yet, the process of evaluation is subjective and varies between people. For example, a government report based on 251 households[7] found that leaving appliances such as televisions or laptops in standby modes (i.e., not disconnected from the power source) adds between £50 and £86 a year to the average UK homeowners energy bills[8] (Zimmerman et al., 2012). For one person, this may seem a pointless cost while for another it may seem a worthwhile price to pay for the convenience of having appliances that can be used more or less immediately without having to wait for "powering up" processes. The subjective nature of evaluation therefore represents an "unknown" in the process and thus there can be no guarantees that feedback will automatically lead to reduced consumption.

Of course the process of evaluation is also likely to be influenced by the strategies that end users employ to judge whether their energy consumption is (un)acceptable. For example, they may assess feedback as "good" when (i) monthly costs remain below a certain threshold or (ii) the visual feedback provided is not negative (e.g., red warning lights, sad faced emoticons etc.) or (iii) because today's consumption was less than yesterday's. Curiously, little is known about the different subjective evaluation strategies that users may adopt and how these impact upon the information attended to and the responses invoked. Yet clearly such knowledge could have important implications for the efficacy of and design of IHDs.

3.5. Personal characteristics and individual differences

According to Van Dam et al. (2010, p. 468), "a one size fits all approach for IHD cannot be justified" because certain groups of people are more receptive to energy saving interventions. Indeed, there is some indication from the literature that consumers' personal characteristics may influence how they use and respond to IHDs (e.g., Murtagh et al., 2014; Pyrko, 2011; Van Dam et al., 2010; Valocchi et al., 2007). For example, Murtagh et al. (2014) found that the energy consumption patterns and conservation attempts varied depending on whether IHD users were categorized as "Monitor Enthusiasts", "Aspiring Energy Savers" or "Energy Non-Engaged". As such, it may be the case that only those with certain traits (e.g., conscientiousness, curiosity) or motives (e.g., environmental, financial) are predisposed to instigate the necessary behavioural processes (e.g., investigation, analysis, and evaluation) that are required to benefit from IHDs. Consequently, IHDs may only appeal to a niche subset of the population and this may limit the overall aggregate effects of feedback on energy consumption. As we have noted, it is also likely that existing research may have overstated the benefits of IHDs. This is because samples are often comprised of volunteers who have willingly elected to participate in an IHD trial (e.g., Hargreaves et al., 2013) and therefore may have an active interest in energy. Findings obtained from such studies are unlikely to be generalizable to the wider population. Indeed, in our own self-selected sample (Buchanan et al., 2014) one consumer wryly noted, "*of course liking anything that tells you how much electricity you're using probably means there's something else missing in your life*". Furthermore, to the best of our knowledge, current policy has not considered individual differences as a factor that may influence the success of feedback in reducing carbon emissions. Yet, clearly an opportunity exists to try and target those for whom IHDs may not naturally appeal – the so called "Energy Non-Engaged" (Murtagh et al., 2014) or the "Energy Stagnant" households that contentedly "consume and pay for the electricity they need and can afford" (Pyrko, 2011, p. 1840). In targeting such consumers, rather than "preaching to the converted", government policy may then have more scope for achieving much wider scale results.

3.6. Reflecting on action potentials – what can we do and what are we prepared to do?

The capabilities of IHD to reduce energy bills are largely dependent on a household's affordances or action potentials – the

[7] According to the report, "A range of householders were selected to match, as closely as possible, the typical English socio-economic mix". However, the report also notes that, "the figures are representative of owner-occupier households rather than the entire English population".

[8] Evidently this figure will vary depending on the number of appliances a household has.

extent to which the circumstances or environment are conducive (or not) to behavioural changes (see also Darby, 2010). There are both actual and perceived action potentials, while the former term refers to "what we can do", the latter refers to "what we are prepared to do".

3.6.1. What consumers can do

Actual action potentials tend to be limited by a person's resources and living circumstances. Indeed, Darby (2010, p. 450) notes that, "some customers will have more power to make changes than others because they have more resources at their disposal and/or because they are allowed to do more". For example, it requires time and capital to research and invest in home improvement measures designed to bolster efficiency, many of which may not offer immediate investment returns, which may be problematic for those who are likely to relocate. For those living in shared and/or rented homes such measures also require permission before progress can begin. Hence, even when feedback may lead motivated users to pursue energy efficiency, their intentions may by thwarted by either actual or perceived action potentials. This is damaging as feedback is likely to be ignored when energy use is considered non-negotiable (Strengers, 2011).

3.6.2. What consumers are prepared to do

Perceived action potentials are subjective and affected by personal and societal norms about which energy-using practises are considered necessary. Such practises are deeply engrained into the fabric of everyday life (Shove, 2010) so that while providing users with an IHD may increase their awareness of such "necessities" or "non-discardable" appliances (Hargreaves et al., 2010, p. 6117), it is unlikely to cause them to be seriously challenged. In our study of users' responses to energy monitors, one woman commented that rather than using her kettle she would heat water with a match under her tea cup (Buchanan et al., 2014). While this remark was intended to be humorous, it is telling that this response came to mind rather than forgoing hot drinks. Similarly, Pierce et al. (2010b) presented examples where occupants were unwilling to change their energy-using practises, even when they were aware that to do so could decrease their consumption. It appears that consumers are reluctant "*to comprise on comfort*" (Buchanan et al., 2014, p. 142), as 56% of respondents of the large scale UK Understanding Society Panel[9] (wave 1, 2009/2010) agreed that any changes they made to help the environment would need to fit in with their lifestyle.[10] Moreover, consumers' own environmental actions are situated in a broader set of social relations (Catney et al., 2013). As such, perceived action potentials are likely to be influenced by consumers' perceptions of the broader social and political context. For example, if IHDs are seen as means of shifting responsibilities for global environmental problems to individuals (Beck and Beck-Gernsheim, 2002; Strengers, 2013, p. 23), then this may limit what consumers are prepared to do, leaving them "frustrated" in the absence of a more "supportive political context" (Hargreaves et al., 2013), in which other agents and institutions (e.g., the government, appliance manufacturers) are also perceived to be undertaking energy savings initiatives.

[9] A longitudinal study that measures key variables relating to the social and economic circumstances and attitudes of people living in the UK. The sample is large and consists of over 40,000 households. For further information please see: https://www.understandingsociety.ac.uk/about

[10] Authors' calculations using University of Essex. Institute for Social and Economic Research and NatCen Social Research, *Understanding Society: Waves 1–3, 2009-2012* [computer file]. *5th Edition.* Colchester, Essex: UK Data Archive [distributor], November 2013. SN: 6614, http://dx.doi.org/10.5255/UKDA-SN-6614-5.

4. The potential for unintended consequences

Evidently the range of human factors involved in IHD interaction means that there is ample opportunity for IHDs to result in unintended consequences. Typically, these have received little attention from either policy makers or researchers. Yet we propose that these unintended consequences warrant attention as they may undermine the capability of IHDs to produce substantial energy reductions and may even have a detrimental impact on vulnerable populations.

4.1. Dangerously cold homes?

Due to a scarcity of research, it is uncertain how households suffering from fuel poverty will react to feedback. This is concerning because, by definition, fuel poor households are poor, cold, or both poor and cold (Palmer et al., 2008). As such, it is likely that their consumption has little scope for further reduction. Consequently, fuel poor households might respond to IHDs by saving a small amount of money but possibly becoming colder as well (Marmot Review Team, 2011). Evidently, this has implications for their well-being as illnesses, such as cardiovascular diseases, increased risk of falls and injuries, are more likely to occur in colder conditions (Public Health England, 2013). Currently, only a few qualitative studies hint at the problems feedback may lead to for low-income or fuel poor households. For instance, one householder trialling an IHD observed that his wife, "*could kind of feel the money seeping out every time she had the boiler on. And to be honest beating herself up over it, you know. 'I can't have it on because I'm wasting money, but I'm cold'*" (Hargreaves et al., 2010, p. 6114). Another study found that an elderly lady receiving feedback felt "*quite proud*" to see that compared to others her consumption was classified as "good" (Barnicoat and Danson, in preparation, case 8). However, if such feelings prompt further aspirations to be "excellent" then this may impact on essential energy use which could be detrimental to her well-being. Evidently reducing carbon emissions at the cost of people's health could be a potentially disastrous outcome of IHDs. This is something that needs to be considered by researchers and policy makers so that steps can be taken to ensure this possibility does not become a reality.

4.2. Legitimizing existing usage

Several studies have observed that feedback can legitimize existing energy consumption. In a qualitative study where 9 Australian households participated in a pilot programme providing feedback via an IHD using a traffic light signals to communicate differing levels of consumption (red for high consumption and green for low consumption), interviewees sometimes interpreted green or orange lights as approval for existing levels of consumption. For example, one householder commented, "*I was always worried about using the dryer so much, but I figure it doesn't make it scream red so it's OK*" (Strengers, 2011, p. 329). Another qualitative study found that UK consumers used IHDs to recognize how "*much energy was required just to keep things ticking over*" or, in other words, to subjectively identify a "*'natural' baseline about which little could be done*" (Hargreaves et al., 2010; p. 6116). Such findings lend credence to concerns that presenting households with knowledge of their baseline may lead them to sustain rather than challenge it (Pierce et al., 2010b). Evidently, this is problematic as it may lead households to overlook possible areas where they might achieve substantial energy savings. For example, householders may view the energy their fridge consumes as part of their "natural" baseline, so it may not occur to them that they could decrease their baseline (and their overall consumption) by replacing it with a more efficient model.

4.3. Rebound effects: spending energy savings on energy consumption

It is now widely recognized that energy savings from technological efficiencies or change are typically overestimated as they fail to take into account rebound effects (Sorrell et al., 2009). Within the field of sustainable consumption, the rebound effect refers to consumers "taking back" the potential energy savings that could be achieved through various behavioural responses (Druckman et al., 2011; Gavankar and Geyer, 2010).[11] For example, despite acquiring a more fuel efficient vehicle consumers may drive further than previously but for the same cost, thus negating any possible fuel savings that may have been achieved had their behaviour remained constant (e.g., Fujii and Ohta, 2010).

In the case of IHDs rebound effects may mean that any energy savings are "reinvested" into the additional consumption of carbon (and/or energy) intensive goods and services. For instance, decreased expenditure on electricity may be counteracted by increased expenditure on gas or cumulative savings may be used to purchase additional electrical appliances or other consumer goods. Researchers have argued that rebound effects are inevitable unless people are intrinsically motivated to conserve energy and are prepared to forgo any of the advantages that could be afforded using the money gained from savings (Otto et al., 2014).

To date, researchers have not examined the extent to which IHDs may lead to rebound effects. However, results obtained from studies of other technologies (space heating, lighting and appliances) suggest that they range between 10% and 30% (Maxwell et al., 2011). Some researchers have argued that such modest effect sizes will not undermine the savings achieved from energy efficiency programs (e.g., Nadel, 2012). Yet, when the overall reductions achieved via feedback are far from substantial at 2% (Delmas et al., 2013), it is concerning that their effects could be further reduced. Consequently, in order to avoid overestimating the energy savings from IHDs, it seems clear that rebound effects need to be taken into account in the potential impact analysis process.

4.4. Boomerang effects: increasing consumption for normality's sake

Interestingly, certain types of feedback may even increase energy consumption if they lead consumers to see that they are low users compared to others. Specifically, studies employing normative statements about energy use have shown that households that are below the norm can increase their usage to conform to typical peer behaviour – a phenomenon referred to as "boomerang effects" (Schultz et al., 2007, p. 439). Boomerang effects have been documented in the literature (e.g., Ayres et al., 2009; Schultz et al., 2007) and have been invoked as an explanation for the relative inability of socially-comparative norm-based feedback to produce significant reductions in consumption (e.g., Fischer, 2008; Harries et al., 2013).

5. Conclusion and policy implications

The increasing global popularity of smart meters and their associated IHDs as part of national roll-out programmes suggests that economically focused feedback delivered via IHDs is being seen as a significant weapon in the fight against increasing carbon emissions and energy demand. Yet, in this viewpoint paper, we sought to challenge this increasingly entrenched view by drawing on existing literature and research to identify the very real challenges that the feedback agenda faces.

Based on the available evidence we note that the effect of feedback on energy consumption is insubstantial with information strategies resulting on average, in short-term reductions of only 2% which may or may not persist in the long term. Of course, to achieve even these initial meager savings, consumers must engage with the IHDs. This necessarily requires enduring levels of interest, environmental and/or financial motivations, and the analytical skills required to both comprehend and evaluate the information that is provided. Naturally, variations in personal characteristics mean that not each and every consumer will have the attributes required to benefit from IHDs. Even if consumers do possess these attributes, the feedback provided may then trigger both abstract and concrete dilemmas where consumers may question what they *should* do in terms of environmental intentions and also struggle to identify what they *can* do in terms of enacting environmental behaviours. Moreover, given that consumers may use and respond to feedback in unexpected ways, there is the potential that IHDS may result in a range of undesirable consequences such as dangerously cold homes for vulnerable populations or legitimizing and/or even increasing existing levels of "over" consumption. Finally, the small energy savings that may be achieved could be counteracted by rebound effects. Evidently then, both "the human factor" and the "potential for unintended consequences" are cause for concern as they can both clearly influence the capabilities of IHDs to reduce (or shift) energy demand.

In the UK, current government policy requires energy suppliers to install 53 million smart meters in domestic homes by 2020 (DECC, 2013a). While we recognize that there may be many reasons for smart metering initiatives and that feedback may be implemented as just one aspect of this policy, a major oft-stated justification is that the provision of IHDs will tackle the issues of rising energy prices by "helping household to cut their energy bills".[12] Yet, as we have demonstrated, simply providing feedback via the proposed IHD is unlikely to produce either substantial or persistent reductions in consumers' energy bills. We suggest that this is primarily because existing IHDs do not have the capability to reduce energy consumption by themselves but rather their success is entirely dependent on user engagement. While this may appear obvious, it seems to us that this "human factor" and the unintended consequences it may prompt have been largely overlooked by both policy makers and researchers. As such, we propose that there is a clear need to reconsider whether investing billions of pounds in providing consumers with the proposed IHDs is a worthwhile endeavour, especially given that they (a) may not benefit consumers and (b) are likely to become outdated fast as, unlike other platforms (e.g., smart phone applications, websites), they cannot be readily updated.

Consequently, we suggest that the challenge is to develop and rigorously test innovative feedback mechanisms that actually engage consumers and take into account the potential shortcomings that we have outlined. One way to do this may be to go beyond existing IHDs that provide only basic cost and consumption information and that require users to invest time and energy in understanding, evaluating, and reflecting on their energy usage. Instead, carefully designed feedback could enable users to readily understand the habits and routines that generate their household energy patterns and thus make more concrete the viable energy saving actions available to them. To date, there has been scarce

[11] Notably, the definition of rebound effects that we use is considerably broader than the definition provided in classical economics theories whereby rebound effects are considered to occur when consumer spend financial savings achieved through price reductions on additional energy consumption. Evidently when defined like this rebound effects may have little relevance to IHDs, unless they are used to encourage peak shifting by implementing time of use tariffs.

[12] https://www.gov.uk/government/policies/helping-households-to-cut-their-energy-bills#history.

research that has considered the design of IHDs, yet some initial findings suggest that the design may influence how readily consumers understand and engage with the feedback provided (Chiang et al., 2012). Given the importance of "the human factor" we argue that any future IHDs should be derived from research that provides comprehensive guidelines about how best to convey feedback in a meaningful way to invoke the desired energy-reduction response. We propose that with these elements in place, there may be some hope that the domestic energy demand reduction aspirations of world-wide smart metering initiatives may be met.

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