Paper presented at the BIEE Conference, Oxford, 18-19 September 2018.

Identifying the limits of the rebound effect

Tina Fawcett, Environmental Change Institute, University of Oxford

Abstract

Delivering energy demand reduction through energy efficiency is probably the single most important strategy in moving to a lower carbon future. However, the efficacy of energy efficiency measures and policies is often challenged with reference to the 'rebound effect', which is variously defined, but whose central claim is that energy efficiency will inevitably lead to lower energy and carbon savings than predicted.

The paper considers the ways that the rebound effect is considered in recent academic literature, incorporated in policy design and used in rhetorical arguments about energy efficiency. The aim is to explore its significance in policy making for the low carbon energy transition.

First the definitions used for the rebound effect in this paper are presented. A summary of evidence on the direct rebound effect suggests it may be between 5-60%, with most estimates at the lower end of the range. In the residential sector, the scale of the rebound effect varies by energy-end use, building type and household characteristics.

There are also many technical and socio-technical reasons why energy efficiency underperforms. These are outlined, with evidence that they can be more significant than the direct rebound effect. The proposed psychological mechanism of 'moral licensing' is shown to be speculative, rather than supported by empirical evidence.

Turning to the indirect rebound effect, the claim that saving money on household energy use could prompt people into taking a long-haul flight is shown to have little basis in reality. The 'reverse rebound effect', where high levels of expenditure on efficiency could remove other expenditure from the economy is illustrated. By this logic, the author's investment in (expensive) insulation saved twice as much carbon through avoided transatlantic flights, than through reduced heating energy.

Currently, the effects of direct rebound are included in some policies, and policy makers are aware of its existence. As future investments in efficiency and low carbon technologies are expected to increase, the reverse rebound effect may become salient in policy-making.

Arguments about the rebound effect can be about something beyond the rebound effect itself. Suggestions include ideological conflicts, an unwillingness to consider evidence, and the attraction of counterintuitive ideas.

The paper concludes that the limits of the rebound effect are varied and likely to change over time. The role of rebound in policy design needs to be based on relevant evidence, and it should not be considered in isolation from other mechanisms which can lead to lower than expected energy savings.

Keyword set

Rebound effect; energy efficiency; policy

Introduction

This paper began in irritation. At academic gathering, yet another person suggested 'energy efficiency is a waste of time, because if people save money on their residential energy bills, they'll just go and spend it on an international flight'. This argument is based on the rebound effect – an effect which leads to lower than expected energy savings from energy efficiency measures, through a variety of mechanisms. So why, to a supporter of energy efficiency, does this argument feel so frustrating? In part, because it contains a kernel of truth. The rebound effect is theoretically established, and has been measured empirically – we know it exists. But this truth is then exaggerated to make claims far beyond the evidence for the nature and scale of actual rebound effects.

This paper explores evidence for and current debates about the rebound effect and considers arguments about its meaning and role in policy. The work is conducted under the UK Energy Research Centre's (UKERC) 'Decision-making theme', where understandings of decision-making, adoption of new technologies, habitual behaviours and changes in behaviour draw on a wide range of theories and empirical evidence. UKERC research also uses building science and socio-technical lenses to understand the 'design-performance' gap. So, this paper does not come from an economics perspective, but seeks to understand how this economic effect fits with other understandings of energy efficiency and lower than expected energy savings. Some arguments are more developed than others - the aim is not to build to a comprehensive thesis, but rather to look at a variety of perspectives on the rebound effect, and to consider what its significance is in policy making for the low carbon energy transition.

Energy efficiency is an important part of current energy policy in the UK and beyond, and is expected to remain a key strategy for delivering the low carbon energy transition (IEA, 2016). Energy efficiency has delivered significant energy savings in the UK in recent years, but this has varied by sector, and is expected to do so into the future:

- For buildings, energy efficiency has been key to reducing demand in the residential sector over recent years and still offers very significant scope for further reductions (Rosenow et al., 2018);
- For industrial energy use, energy efficiency has delivered approximately one third of the savings due to reducing energy intensity (Hardt et al., 2018);
- For transport, vehicle energy efficiency has failed to deliver decreases in energy use by the sector, with considerable concern recently on the mismatch between test and real world energy efficiency ratings (Brand, 2016).

Because energy efficiency is important, so too is the rebound effect. As Gillingham et al. (2016) note:

> *"The debate about the magnitude of the rebound effect continues and has important implications for energy efficiency policy."* (Gillingham et al., 2016:84)

There is an argument that failure to take account of rebound effect could lead to not saving enough energy to meet energy and climate policy goals (e.g. Sorrell, 2007). Alternatively, if the idea of rebound is misused and its scale exaggerated, this could lead to under-investment in energy efficiency by policy makers because they undervalue its potential contribution.

This paper is exploratory: the methodology has been a selective literature review. First the definitions used for the rebound effect in this paper are set out, followed by a summary of evidence on the scale of the direct rebound effect. Then a variety of different explanations for lower than expected energy savings are presented. Arguments based on the indirect rebound effect are explored, and the 'reverse rebound effect' illustrated. The role of the rebound effect in policy making is considered. The paper closes with a discussion and brief conclusions.

Definitions

Sorrell (2007) summarised the state of the literature in his extensive and authoritative review:

"Rebound effects are very difficult to quantify, and their size and importance under different circumstances is hotly disputed. Also, rebound effects operate through a variety of different mechanisms and lack of clarity about these has led to persistent confusion." Sorrell (2007:v)

To try and avoid confusion within this paper, the following definitions of components of the rebound effect are used:

Direct rebound effect – users taking advantage of the new lower price of the energy service to use more of that service (typical example is having a warmer home after efficiency improvements, or driving further as a result of higher efficiency engines or lower total driving costs per km).

Indirect rebound effect – money saved as a result of energy savings is spent elsewhere in the economy on goods / services which have embodied energy and/or direct energy use.

Macroeconomic growth effect – the fall in service cost reduces the price of other goods, creates new production possibilities and increases economic growth, which in turn increases energy use.

The macroeconomic growth effect is central to claims of 'backfire' - the idea that energy efficiency actually leads to increased energy consumption, through economic growth. It is the component of the rebound effect with the least concrete evidence (Gillingham et al., 2016), and is arguably of least relevance for policy making. It is not discussed in any detail in this paper.

The direct rebound effect can be measured empirically (although see discussion below). The indirect rebound effect can be modelled. Whether the economy-wide / macro-economic growth effect can be reliably modelled is open to debate (Gillingham et al., 2016).

Scale of the direct rebound effect

Evidence about the scale of the rebound effect generally comes from measurements of the direct rebound effect. There is a range of estimates:

- Chitnis et al. (2013) estimate that it is 5-15% for UK residential energy
- Gillingham et al (2016) state that rebound effects are generally 'less than 10 percent, and unlikely to exceed 60 percent.'
- Greening et al. (2000) conclude that 'For the energy end uses for which studies are available, … the range of estimates for the size of the rebound effect is very low to moderate.'.
- Sorrell et al. (2009) state that for household energy services in the OECD, the direct rebound effect should generally be less than 30%

Clearly there is quite some difference between 5% and 60%, and this matters considerably in policy and programme design.

Rebound varies by social circumstance and energy end-use. Much of the research has been carried out on household heating: where people are living in cold homes and are inadequately warm, an important benefit of energy efficiency is that it allows affordable comfort. It has been long-established that those who have under-heated homes are like to take more of the benefits of efficiency as comfort (Milne and Boardman, 1997). However, as the efficiency of homes in the UK has risen, there is evidence that the rise in average internal temperatures which has been seen over recent decades is levelling off (Oreszczyn, 2018). The demand for additional energy services is contingent on circumstances, varies by energy end use, and is likely to change over time – as will the scale of the direct rebound effect.

Other explanations for lower than expected savings from efficiency

Some authors suggest it would be helpful to broaden the definition of the rebound effect, for example:

> *"… the assumption that all rebounds are due to rational economic behavioral effects needs to be questioned. Rebound effects also occur through social-structural changes, technical failures, and mismatches between technology and its users."* (Galvin & Sunikka-Blank, 2017: 385).

In this paper, the rebound effect has been defined in the more usual way, based on economic reasoning. Nevertheless, as Galvin and Sunikka-Blank point out, there are other social, technical and socio-technical mechanisms at work which can also reduce energy savings compared with those expected. These are discussed briefly below, with a special focus on the proposed 'moral licensing' psychological mechanism.

Technical and socio-technical explanations

There are many reasons beyond the rebound effect why energy efficiency might not deliver full expected savings. In the buildings sector this phenomenon is a component of the 'design-performance gap'.

The reasons for a difference between anticipated and actual energy savings include:

- efficiency not as high in reality as reported via the energy label / test standards;
- the efficient technology is installed badly, and/or controls and systems are poorly designed;
- users are not enabled to use the new thing 'correctly' (wasting energy, rather than getting additional energy services);
- the wrong baseline assumption about energy use 'before' the intervention.

The recent example of 'Dieselgate' has highlighted the potential seriousness of differences between declared and actual efficiency for new cars. Evidence has shown that real world CO_2 emissions are on average a third higher than test declarations, and that this discrepancy has increased markedly over recent years (Brand, 2016).

Experience with heat pump installations for space heating in the UK has shown that the measured efficiency of heat pump systems has been less than expected, with many monitored systems only operating at 2/3 of the performance expected. This is largely due to the poor quality, integration and intelligibility of controls, and system designs surrounding the heat pumps, rather the efficiency of the central technology itself (Fawcett, 2011).

Technologies are embedded in socio-technical systems. If this is done such that users cannot use them efficiently to meet their needs, energy can be wasted. There are many examples of this following efficiency improvements to buildings (Topouzi, 2015).

If lower than average energy savings are experienced ex post, this may be because the calculation of expected savings was based on incorrect ex ante assumptions. For example, older, less efficient buildings are heated to lower temperatures than newer buildings (Hamilton et al, 2016). Energy that was never used in the first place can't be saved.

The scale of these different effects varies - and the examples above are illustrative only, and very far from a full literature review - but it is fair to say two things:

(1) they may be more significant than the direct rebound effect;
(2) their existence means that any empirical evidence about the gap between anticipated and actual energy savings has to consider a range of explanations, not just the rebound effect.

Psychological explanations: moral licensing

Sometimes ‘moral licensing’ is mentioned in broader (non-economic) discussions of rebound - the claim being that investing in energy efficiency / saving energy will engender consequent environmentally damaging behaviours. Moral licensing theory suggests that “past good deeds can liberate individuals to engage in behaviors that are immoral, unethical, or otherwise problematic, behaviors that they would otherwise avoid for fear of feeling or appearing immoral” (Blanken et al., 2015). For example, someone who has just spent some time volunteering for the local community centre might later find it more acceptable to ‘forget’ to report some additional income when filling out the tax return.

Blanken et al (2015) conducted a meta- analysis of 91 studies of moral licensing. One reason for the study was their observation that the moral licensing effect seemed to conflict with one of the most established psychological findings - that people want to be and appear consistent in their behaviour. They were also concerned about the low replicability of moral licensing studies. Most studies in the meta-analysis looked at choices or intentions around volunteering / charitable donations, honesty with money, and racial prejudice. A small number of the studies concerned environmental choices, none of which were related to energy or energy efficiency.

They concluded that the magnitude of the moral licensing effect is lower than typical effects in social psychology, and that there is a publication bias – those studies published show a larger effect than those which have not been published. Thus, at present the case for proposing moral licensing as a significant mechanism for influencing energy-related choices is insufficiently made.

Arguments based on the indirect rebound effect

The indirect rebound effect cannot be measured - estimates are based on modelling, which has to make assumptions about how any spare income (due to energy savings from efficiency) will be spent. The embodied or direct energy use as a result of that expenditure then offsets some of the savings from efficiency. Different assumptions which can be made about additional or reduced expenditure are shown in Figure 1[1]. The neutral assumption would be that expenditure is on averagely energy intensive goods and services (or average for marginal expenditure). However, in debates about the rebound effect, as noted in the introduction, assumptions are made that any savings will be spent on high carbon goods and services.

Not all energy efficiency measures are cost-effective - they may be adopted for other reasons (e.g. concern about greenhouse gas emissions, to increase comfort, indoor air quality or status). In these cases, investing in efficiency will remove expenditure from the economy that would have been spent on other goods and services. This could be called the ‘reverse rebound effect’– which although recognised within the literature is seldom referenced in public debate.

Use of air travel in rhetoric

The possibility of savings from household energy efficiency being spent on air travel is frequently referenced in the literature (Corner and Clarke, 2017; Herring and Roy, 2007; Jackson, 2017).

The following are typical formulations:

> *“An example of a rebound effect would be … a family that insulates their loft and puts the money saved on their heating bill towards an overseas holiday.”(UKERC, 2007)*

[1] More sophisticated modelling of the indirect rebound effect and more subtle theoretical distinctions between different income and substitution effects are undertaken than depicted in Figure 1 (e.g. Gillingham et al, 2016).

> *"A good example of a 'rebound' effect would be an individual deciding to 'treat themselves' to a foreign holiday with the money they had saved on the energy bill through insulation measures…" (Corner and Clarke, 2017:76)*

Chitnis et al. (2013) wrote a paper called 'Turning lights into flights: Estimating direct and indirect effects for UK households', echoing the slogan from a UK supermarket's marketing campaign.

There is no reason to assume this this expenditure would result in other than average C emissions per £ across all consumer spending. Air travel is probably the most greenhouse-gas intensive option per £ spent - which is what makes it rhetorically powerful.

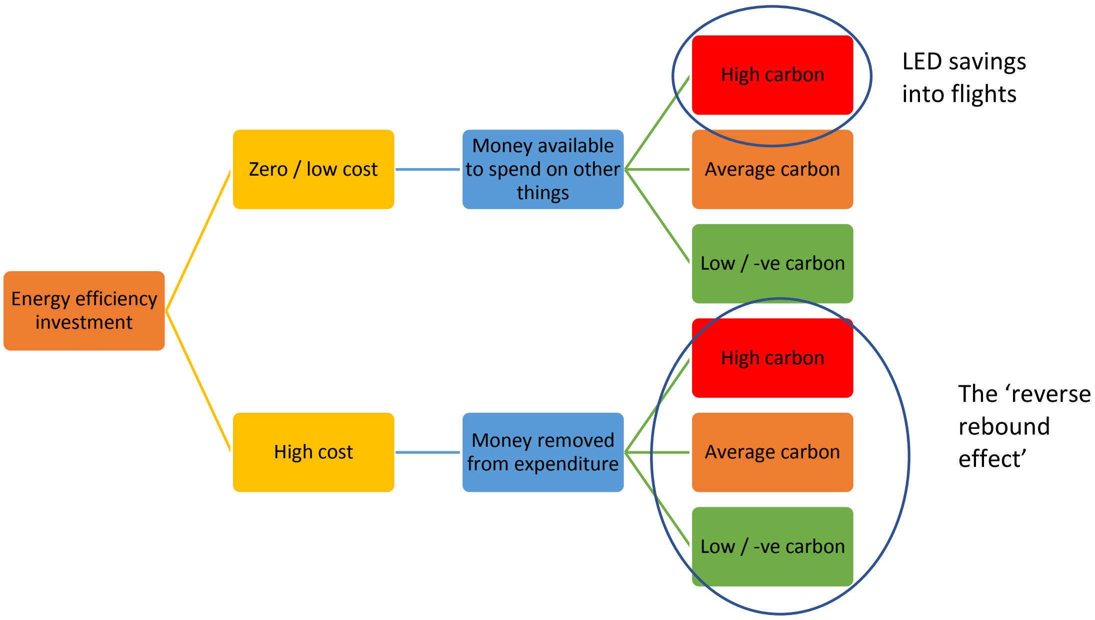

Figure 1: The indirect rebound effect - possible pathways

'Reverse rebound effect'

Most discussions about the indirect rebound effect assume that energy efficiency options will result in cost savings to their adopter. However, expenditure on energy efficiency may not 'pay back' to the adopter. In the future, if low carbon targets are to be met, more expensive efficiency and low carbon measures will have to be adopted. For example, in the residential sector investment in whole-home retrofit and low carbon heating systems are not necessarily going to be 'win-win' (Webb, 2016).

The effects of the reverse rebound effect could be significant, particularly if we make the assumption that the expenditure removed would have been spent on high carbon goods / services. For illustration, the following example comes from my own experience.

In my home, I have spent considerably more money on energy efficiency measures, particularly to reduce heating energy use, than will be paid back in energy savings. The surplus expenditure approximately equates to the cost of 20 return flights from Heathrow to New York.

Post-renovation energy measurements have shown the energy efficiency improvements have delivered annual savings of about ≈ 3,000kWh gas for space heating. Using the standard conversion figure for natural gas, this is equivalent to an annual reduction in emissions of 0.57 tCO_2 . (As these are measured figures, if there has been any direct rebound, energy savings figures already take this into account.)

Carbon equivalent emissions from round trip to New York, according to Climatecare = 1.52 tCO_2 (note that turning flight distances into carbon equivalent emission is scientifically uncertain, with a lack of consensus on what figure should be used for radiative forcing.)

Flights avoided = 30 tCO_2 which is about 50 times more carbon than that saved per year from the insulation measures.

If we assume that the insulation measures will last for 25 years, then the avoided flight savings are two times lifetime savings – which would mean that the carbon savings ascribed to the insulation measures should be tripled.

While this example is doing what was criticized in the previous section - making the unwarranted assumption of high carbon expenditure (avoided expenditure in this case) - it does illustrate the point that if the rebound effect is to be taken account of in policy making (and it is), the reverse rebound effect also matters. This will particularly be the case into the future with greater investments in efficiency required.

Policy and the rebound effect

As noted in the introduction, the debate about the magnitude and nature of the rebound effect has important implications for energy efficiency policy. The direct rebound effect has been taken account of in some energy efficiency policies - in the sense that expected savings are reduced. Font-Vivanco et al. (2016) identify examples of this:

- Energy savings are reduced by an 'In Use Factor' in UK energy company obligation schemes. This varies with technology & includes the direct rebound effect;
- Ireland assumes a rebound effect of 70% associated with comfort taking in low-income households;
- U.S. Department of Energy includes a 10% rebound effect from car standards into its energy forecasting.

Font Vivanco et al. argue that, in general, the rebound effect is not sufficiently taken account of in policy.

It is possible, in theory, to design policy so as to exclude the direct and indirect rebound effects - if the more efficient energy service is the same price as that prior to intervention. The UK's Green Deal policy – which was policy of loans for household energy efficiency investments which would be paid back via electricity bills – could have had zero direct and indirect rebound effect. This is because the maximum loan offered was set at the rate so that total expenditure by households on loan + energy was the same as the energy expenditure beforehand. The Green Deal also attempted to estimate more accurate energy savings by basing calculations on individual household audits (so getting a better baseline for 'before' energy use). However, while this gave householders better information, it added to the expense and complexity of the policy. The Green Deal which proved to be unsuccessful, for a variety of reasons, and was withdrawn (Rosenow and Eyre, 2016).

Research about how EU and UK NGOs talk to politicians and policy makers about energy efficiency, touched on the rebound effect. The interviews with NGOs showed that they found a multiple benefits/impacts framing useful to demonstrate how energy efficiency could be a positive solution in a range of spheres, from health to air quality to jobs and economic growth (Fawcett and Killip, 2017). The multiple benefits framing explicitly acknowledges that energy saving is not the only, or necessarily the most important, benefit of energy efficiency (IEA 2014). The rebound effect was identified by a UK interviewee as the one negative effect of efficiency commonly raised by politicians and policy makers:

> *"The one that does come up is rebound. That's the one that always comes up and, frankly, I just produce the solid evidence there is that a) that is not an entirely negative thing, depending on what the rebound is, and b) that there's no good evidence to suggest that you get any kind of backfire."*

This quote also highlights that energy efficiency can be used to meet multiple policy goals. For the UK's energy company obligation schemes 2008-12 (known as CERT and CESP), nine different policy objectives were listed (ENSPOL 2015). As Hertwich (2005:90) noted:

> *"The rebound debate reflects a concern about indirect effects that affect the ability of a primary policy measure to achieve its goal."*

So where energy saving is just one goal of the policy – for example in improving the efficiency of the homes of the fuel poor – it is fair to consider 'take back' of comfort as a rebound effect? Does or should the policy intent define how and whether we talk about the rebound effect?

What are arguments about the rebound effect really about?

There is a case for thinking that arguments about the rebound effect can be about something beyond the rebound effect itself.

For example, Rowson (2013) suggests that in the absence of clear evidence, "disagreement about the size of the rebound effect looks like a proxy war for deeper ideological conflicts". He suggested that 'ecological modernisers' *want* rebound to be low because that fits with a worldview whereby economic growth and environmental improvement can be delivered by technological and efficiency improvements. Whereas those who *want* the rebound effect to be large, favour interventions relating to values and changes in social practices in order to deliver wholesale social and economic transformation. This is a provocative stance - but it is worth reflecting upon.

From a different viewpoint (presumably) Nordhaus (2017) states: *"the rebound debate mostly obviously shows how our beliefs about how the world ought to work influence our willingness to accept some scientific findings and our inclination to reject or ignore others"*. Although this may be code for suggesting the people who don't share his interpretation of the rebound effect are ignoring the evidence – it nevertheless indicates how the rebound effect is connected to (or is thought to be connected to) wider beliefs and assumptions.

There is an alternative interpretation of how the rebound effect is reported in the popular media. Gillingham et al., (2016) suggest it receives significant attention because 'counterintuitive results' are favoured. Stories about the rebound effect then would sit in the same category as the attention paid to fitness advocates who die from heart attacks, or the 100 year old who smokes 20 a day. This desire to report the counterintuitive could stem from different impulses - for example, a legitimate wish to highlight contradictions in public policy, or, more negatively, the search for stories that justify adhering to damaging choices and behaviours (using energy inefficiently, not exercising, smoking).

Further, some commentators who raise the issue of the rebound effect that governments should not mandate efficiency improvements, and should focus on low carbon sources of energy instead. A more extreme – possibly mischievous - version of this argument is that, because of the backfire effect, less rather than more energy efficient goods should be promoted, to reduce energy use (The Economist, 2010).

Contrary to Rowson's suggestion, the impulse to report counterintuitive results does not seem to stem from favouring more radical social change. Thus, while arguments about the rebound effect may be drawing on other values and concerns, these are likely to vary.

Discussion & conclusions

Rebound as one explanation among many

There are many reasons why energy efficiency may deliver less than the expected energy savings - the rebound effect is just one of these. The rebound effect itself is a suite of economic mechanisms, only one of which – the direct rebound effect – is measurable (bearing in mind it tends to co-exist with other confounding factors). Other technical or socio-technical causes of low energy savings can be more important than the rebound effect. However, the proposed 'moral licensing' effect of investing in energy efficiency is not supported by the evidence.

Rebound versus multiple benefits

In some cases the key purpose of a policy supporting energy efficiency, or investment in energy efficiency, is not to save energy. For example, improving energy efficiency in the homes of people in fuel poverty can be primarily to enable them to be sufficiently warm. Although this comfort improvement can be labelled as 'rebound', that is not necessarily accurate, or helpful, as the inference is that is an undesirable or unforeseen policy outcome.

Reverse rebound

The reverse (indirect) rebound effect is just as valid theoretically as the indirect rebound effect. As with the indirect rebound effect, it can only be modelled and its scale depends on the assumptions made. However, it could be important in thinking about the additional benefits of a policy which, say, involves higher costs to consumers for more efficient products / cars / homes. Given that upcoming low carbon technologies - heat pumps, electric vehicles etc. - are like to be more expensive than their fossil fuel alternatives, this perspective may become more relevant.

Changing nature of rebound

The direct rebound effect is expression of unmet demand, which is particularly significant in badly insulated homes, or for those living in fuel poverty. It is likely to fall over time for heating energy in the residential sector as average indoor temperatures rise and as the housing stock becomes more efficient. As the wider economy decarbonises, the indirect rebound effect too should become less problematic (assuming the key policy concern is about carbon emissions as a result of energy use, not energy use in itself). These future changes to the scale of rebound are worth further exploration.

Policy

Policy design can take account of the direct rebound effect when setting efficiency or adoption targets - although many policies do not. It might also be possible to design out the direct and indirect rebound effect, as seen in the Green Deal, although given the extra complexity involved it is questionable whether this is proportionate to the problem. The role of rebound in policy design needs to be based on relevant evidence, and it should not be considered in isolation from other mechanisms which can lead to lower than expected energy savings.

Meanings

Some of the commentary on the rebound effect is probably mischievous or misguided. This should perhaps not been taken too seriously - however irritating it might be. However, the suggestion that interpretations of data (or lack of data) can be linked to deeper concerns or worldviews cannot be so easily dismissed, and are worth reflection.

Concluding thoughts

In some cases, the rebound effect is significant in scale and should be incorporated in policy designs; in other cases it is very minor, and a distraction. Given the incomplete evidence base, telling the difference isn't always easy. In addition, the scale of rebound is likely to change over time. As a starting point, the rebound effect should be carefully defined, and considered alongside other potential causes of underperformance of energy efficiency measures or policies, which require quite a different response. Understanding energy demand in its full socio-technical context, in addition to its economic context, should help build more robust policy.

And finally, this paper has shown there is no evidence to suggest that people are converting savings from light bulbs into flights – either as an indirect rebound, or through moral licensing. So next time this comes up in discussion, irritation can be replaced by elucidation.

Acknowledgements

This work was supported by the UK Energy Research Centre, which is funded by the UK Research Councils [EPSRC award EP/L024756/1].

References

Blanken, I., van de Ven, N., Zeelenberg, M., 2015. A Meta-Analytic Review of Moral Licensing. Personality and Social Psychology Bulletin 41, 540-558.

Brand, C., 2016. Beyond 'Dieselgate': Implications of unaccounted and future air pollutant emissions and energy use for cars in the United Kingdom. Energy Policy 97, 1-12.

Chitnis, M., Sorrell, S., Druckman, A., Firth, S.K., Jackson, T., 2013. Turning lights into flights: Estimating direct and indirect rebound effects for UK households. Energy Policy 55, 234-250.

Corner, A., Clarke, J., 2017. Talking climate: From research to practice in public engagement. Palgrave MacMillan, Cham, Switzerland.

ENSPOL, 2015. D2.1.1: Report on existing and planned EEOs in the EU. Part 1: Evaluation of existing schemes. Available: http://enspol.eu/results [Accessed September 2018]

Fawcett, T., 2011. The future role of heat pumps in the domestic sector, European Council for an Energy Efficient Economy Summer Study, Hyeres, France.

Fawcett, T., Killip, G., 2017. INBEE project: Exploring practitioner experience of using multiple impacts arguments in policy debates. .

Font Vivanco, D., Kemp, R., van der Voet, E., 2016. How to deal with the rebound effect? A policy-oriented approach. Energy Policy 94, 114-125.

Galvin, R., Sunikka-Blank, M., 2017. Ten questions concerning sustainable domestic thermal retrofit policy research. Building and Environment 118, 377-388.

Gillingham, K., Rapson, D., Wagner, G., 2016. The Rebound Effect and Energy Efficiency Policy. Review of Environmental Economics and Policy 10, 68-88.

Greening, L., A., Greene, D.L., Difiglio, C., 2000. Energy efficiency and consumption — the rebound effect — a survey. Energy Policy 28, 389-401.

Hamilton, I., Summerfield, A.J., Shipworth, D., Steadman, J. P., Oreszczyn, T., Lowe, R.J., 2016. Energy efficiency uptake and energy savings in English houses: A cohort study. Energy and Buildings 118. Pp 259-276

Hardt, L., Owen, A., Brockway, P., Heun, M.K., Barrett, J., Taylor, P.G., Foxon, T.J., 2018. Untangling the drivers of energy reduction in the UK productive sectors: Efficiency or offshoring? Applied Energy 223, 124-133.

Herring, H., Roy, R., 2007. Technological innovation, energy efficient design and the rebound effect. Technovation 27, 194-203.

Hertwich, E.G., 2005. Consumption and the Rebound Effect: An Industrial Ecology Perspective. Journal of Industrial Ecology 9, 85-98.

IEA, 2016. Energy efficiency market report 2016. International Energy Agency, Paris.

IEA 2014. Multiple benefits of energy efficiency. International Energy Agency, Paris.

Jackson, T., 2017. Prosperity without growth: Foundations for the economy of tomorrow, Second edtion ed. Routledge, Abingdon, Oxfordshire.

Milne, G., Boardman, B., 1997. Making cold homes warmer: the effect of energy efficiency improvements in low income homes. Eaga Partnership Charitable Trust.

Nordhaus, T., 2017. The Energy Rebound Battle. Issues in science and technology 37(4), Available: http://issues.org/33-4/the-energy-rebound-battle/ [Accessed September 2018]

Oreszczyn, T. 2018. Personal communication, August 2018.

Rosenow, J., Eyre, N., 2016. A post mortem of the Green Deal: Austerity, energy efficiency, and failure in British energy policy. Energy Research & Social Science 21, 141-144.

Rosenow, J., Guertler, P., Sorrell, S., Eyre, N., 2018. The remaining potential for energy savings in UK households. Energy Policy 121, 542-552.

Rowson, J., 2013. A new agenda on climate change: Facing up to stealth denial and winding down on fossil fuels. Royal Society of the Arts, Online: https://www.thersa.org/discover/publications-and-articles/reports/a-new-agenda-on-climate-change [accessed Nov 2017].

Sorrell, S., 2007. The Rebound Effect: an assessment of the evidence for economy-wide energy savings from improved energy efficiency. UK Energy Research Centre, Online: http://www.ukerc.ac.uk/programmes/technology-and-policy-assessment/the-rebound-effect-report.html [Accessed Nov 2017].

Sorrell, S., Dimitropoulos, J., Sommerville, M., 2009. Empirical estimates of the direct rebound effect: A review. Energy Policy 37, 1356-1371.

The Economist, 2010. Not such a bright idea 28 August 2010. Available: https://www.economist.com/science-and-technology/2010/08/26/not-such-a-bright-idea [Accessed September 2018]

Topouzi, M., 2015. Occupants' interaction with low-carbon retrofitted homes and its impact on energy use, Environmental Change Institute. University of Oxford, Oxford.

UKERC, 2007. The rebound effect report. UK Energy Research Centre, http://www.ukerc.ac.uk/programmes/technology-and-policy-assessment/the-rebound-effect-report.html.[Accessed August 2018]

Webb, J., 2016. Heat and energy efficiency: making effective policy. A report for the UK Committe on Climate Change. University of Edinburgh, Available: https://www.theccc.org.uk/wp-content/uploads/2016/10/Heat-and-Energy-Efficiency-Advisory-Group-Report-Making-Effective-Policy.pdf [Accessed August 2018].