PHASE 1 FINAL REPORT:

The Rebound Effect for Developing Countries

Economic Consulting Associates

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EVIDENCE ON DEMAND
CLIMATE & ENVIRONMENT
INFRASTRUCTURE | LIVELIHOODS

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What is the rebound effect?

First identified by W.S. Jevons in 1865, the rebound effect is defined as the unintended consequences of energy efficiency (EE) improvements which prevent the full realisation of the expected technical energy savings. In other words, through the rebound effect, some parts of the anticipated reduction in energy consumption, based on *ex-ante* engineering or technical estimates, are offset by the increased demand for energy services as a result of a decrease in their relative price[1]. Although rebound is often discussed in the context of energy efficiency, its application is useful with regard to the measures which seek to displace energy consumption through substitution of an alternative energy form; eg, solar lanterns as a substitute for kerosene lamps.

Formally, the rebound effect is measured as the proportion of technically achievable reductions in energy consumption from efficiency improvements that is not realised[2]. Consequently, the rebound effect is usually represented as a percentage of the potential energy savings. A 10% rebound effect implies that only 90% of the technically achievable efficiency will actually be realised.

Three different types of rebound effects can be identified:

- ***Direct rebound effect*** – The effect of the efficiency improvement on the consumption of the more efficient energy service.
- ***Indirect rebound effect*** – The effect on consumption of other energy intensive goods and services as a result of increased efficiency of one energy service.
- ***Economy-wide effect*** – the effect of increased efficiency, and related productivity, of one energy service on the consumption of inputs and energy services in the economy overall. In theory, the economy-wide effect is the sum of the direct and indirect effects if all the latter could be identified and measured.

How large is the rebound effect?

A total of 163 academic papers and other published studies containing a total of 241 different reported estimates of the magnitude of rebound effects were reviewed in the preparation of this report. However, only a small proportion of these have been judged to be of sufficient quality to be used as reliable sources of evidence on the magnitude of the effect. These studies are heavily concentrated in high-income countries and in residential uses.

From this review, the following proposed ranges for estimates of the rebound effect to be used in options analysis have been derived. These ranges are inevitably somewhat subjective but represent a considered judgement of what is a reasonable value based on the limited available evidence.

1 Barker et al. (2009)
2 Murray (2012)

			Residential - Heating	Residential - Other	Industrial and Commercial
Country group	*High Income*	Direct effect	20-40%	0-20%	0-20%
		Total / economy-wide effect	40-60%	10-30%	20-40%
	Middle + Low Income	Direct effect	--	10-30%	0-20%
		Total / economy-wide effect	--	30-50%	20-40%

Table 1 Rebound effect estimates for project analysis

Indirect effects are not separately identified, but can be assumed to be the difference between the total or economy-wide effect and the direct effect. We have not provided estimates for rebound effects in space heating in middle and low-income countries on the grounds that these countries generally have less need for these services.

To help select a value within these ranges, we have prepared a checklist of qualitative factors to be considered. We use an illustrative classification of '+' (increases the rebound effect) and '-' (reduces the rebound effect).

Factors	Impact on direct rebound effect	Impact on indirect rebound effect
High income level of consumers	--	--
High existing efficiency of energy services	--	--
High existing true cost of the energy services	+	+
High capital costs associated with energy efficiency improvement incurred by the consumer	--	--
Separation between payee and user	--	--
Commercial sector compared to residential sector	--	--
Rigidities in markets	+	+
High energy to total cost ratio (industrial sector)	+	+
High availability of the energy service	+	--
High income inequality	+	+

Table 2 Qualitative factors and their impact on rebound effects

How to include the rebound effect in analysis?

There are three types of intervention where adjustments for the rebound effect should be considered:

- Interventions which replace a higher energy consuming good with a lower energy consuming good
- “Soft” interventions concerning communication, awareness raising, and policies such as building codes
- Interventions not technically leading to a rebound effect but with rebound effect-like characteristics.

For the first, the rebound effect, adjusted where considered necessary, can be applied to the estimated technical savings to develop an estimate of probable savings as opposed to technical savings. For the second, or soft interventions, the application of the rebound effect will depend on the type of approach utilised to estimate the savings. Where the savings are estimated based on estimates of uptake and utilisation of a specific measure, then the application of the rebound effect is as with the first type of intervention – application of the appropriate rebound effect to the technical savings. Where the approach to estimating savings is based on a metric which captures MWh savings per £ of expenditure, then one must evaluate whether the captured savings associated with the metric are likely to have a rebound effect higher or lower than the environment into which the intervention is being placed. Finally, for interventions with rebound effect-like characteristics, the application of the rebound effect can follow the same approach as if it were a precise rebound effect.

No adjustment should be made to estimates of changes in social welfare, as a result of the inclusion of the rebound effect. The welfare value of the cost savings from energy efficiency is assumed to be the same whether spent on increased energy consumption (the rebound effect) or on other goods and services. Not making this assumption would amount to double-counting of these welfare impacts. The rebound effect, therefore, will primarily impact on the magnitude of the GHG savings resulting from an intervention.

SECTION 1

Introduction and purpose of this report

This paper presents the evidence of an extensive review of the literature on rebound effects for energy efficiency and renewable energy measures. The objective of the paper is to provide the Department for International Development (DFID), the International Climate Fund (ICF) and potentially other agencies a guide for the inclusion of rebound effects into option appraisals.

The rebound effect, i.e. the increase in the consumption of an energy service resulting from an increased efficiency (and reduced cost) of that service, varies across sectors, countries and agents. Although the rebound effect is to be considered in the context of developing countries, there are only a handful of studies which seek to estimate the rebound effect in such nations, with studies instead heavily biased towards to the developed world. The estimates of the magnitude of this effect in developing countries presented in this report, therefore, are inevitably heavily reliant on these developed country studies. The report does note where different values might be expected to apply in developing countries.

The first part of this report (Section 2) describes the rebound effect conceptually. The second part (Section 3) provides estimates of the magnitude of the rebound effect. The third part provides guidance on how to select an appropriate value for analytical purposes. The fourth part (Section 5) discusses how the rebound effect can be incorporated into options analysis conducted by DFID and ICF.

There are also two appendices. The first (Appendix A) provides an overview of the literature discussing how the magnitude of the rebound effect is estimated and how we have assessed the quality of the evidence presented by the studies. The second (Apendix B) contains a list of literature and other references consulted.

SECTION 2

What is the rebound effect?

Definition

First identified by W.S. Jevons in 1865[3], the rebound effect is defined as the unintended consequences of energy efficiency (EE) improvements which prevent the full realisation of the expected technical energy savings. In other words, through the rebound effect, some parts of the anticipated reduction in energy consumption, based on *ex-ante* engineering or technical estimates, are offset by the increased demand for energy services as a result of a decrease in their relative price[4].

Formally, the rebound effect is measured as the proportion of technically achievable reductions in energy consumption from efficiency improvements that is not realised[5]. Consequently, the rebound effect is usually represented as a percentage of the potential energy savings. A 10% rebound effect implies that only 90% of the technically achievable efficiency will actually be realised[6].

A rebound effect exceeding 100% is defined as 'backfire' (i.e. the technical estimates of energy savings are more than offset by the rebound effect). There is extensive debate in the literature over whether backfire is a reality. If it is, then it would imply that, where the objective of an intervention is to reduce energy consumption, the promotion of energy efficiency is counter-productive. However, it is extremely important that this is not taken to mean promotion of energy efficiency is not desirable. Whether backfire actually exists is questionable. And a focus on backfire ignores the wider social welfare benefits of increasing access to energy services through energy efficiency measures by lowering the effective cost of their consumption. For lower-income countries, where wealth and income constraints on consumption are higher, this effect may lead to poverty reduction effects that outweigh any potential welfare reductions resulting from backfire.

Three different types of rebound effects have been identified in environmental economics literature:

- ***Direct rebound effect*** – The effect of the efficiency improvement on the consumption of the more efficient energy service.
- ***Indirect rebound effect*** – The effect on consumption of other energy intensive goods and services as a result of increased efficiency of one energy service.
- ***Economy-wide effect*** – the effect of increased efficiency, and related productivity, of one energy service on the consumption of inputs and energy services in the economy overall.

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3 Jevons (1865)
4 Barker et al. (2009)
5 Murray (2012)
6 Theoretically, estimates of technical efficiencies should be adjusted for deficiencies and underperformance. In reality, it may be difficult to separate these out. As underperformance and deficiencies have been problematic in a number of interventions introduced into the developing world, their role should thus not be discounted when considering estimated magnitudes of the rebound effect.

In theory, the sum of direct and indirect rebound effects sum to the economy-wide effect.

Figure 1 provides an illustration of the different types of rebound effects.

Figure 1 Illustration of different types of rebound effects[7]

'Engineering' estimate of energy savings	**Actual energy savings**		
	Economy-wide rebound effect	**Indirect rebound effect**	**Secondary effects**
			Embodied energy
		Direct rebound effect	**Income/output effect**
			Substitution effect

Direct rebound effect

Direct rebound effects are a micro-economic phenomenon in which the introduction of an energy efficiency improvement increases the overall demand from the consumer for the same energy service. For example, the introduction of compact fluorescent lamps (CFLs), which result in a reduction in the amount of energy required to produce the same level of light, leads to an increase in the number of hours during which the lights are kept on during a given day.

This direct effect is the result of a change in the implicit price of the energy service due to a reduction in the energy required to provide the service. As the implicit price falls, demand for the service increases given the additional income available from the implicit price drop *and* through the substitution of other goods or services by this now relatively lower priced energy service. These two effects are better known in economics as the **income effect** and the **substitution effect**, respectively.

An illustration of the direct rebound effect in the context of improved cook stoves is shown in Box 1.

Box 1 Improved cook stoves and the rebound effect

Technical estimates of the fuel savings from improved cook stoves vary between 10 and 60%. As the implicit price of cooking with biomass (usually charcoal) decreases from switching to an improved stove, households will see an increase in their income as less is spent on biomass, which in turn will lead to increased use of the stove. This is known as the income effect. A decrease in the implicit price also means that use of the biomass stove has now become cheaper relative to other cooking options. Households may then cook a meal with biomass rather than kerosene. This is known as the substitution effect. The income and substitution effects together make up the price or direct effect.

The existence and impacts of this effect in the context of cooking stoves have been confirmed by a number of studies. For example, in urban Senegal, Bensch & Peters (2011) show that, where charcoal is the principal energy source for the improved stoves, average

7 Source: Sorrell (2007)

savings per dish compared to a traditional charcoal stove are 25-26%. However, in aggregate, total charcoal savings are entirely lost as households choose to prepare more hot dishes.

In the Sudan, Zein-Elabdin (1997) estimated the rebound effect associated with improved cook stoves as being around 40%. In this instance, the driver was changes in relative prices rather than the income effect. The primary cause was attributed to rigidities in the charcoal supply chain which meant that supplies of charcoal failed to reduce significantly with reduced demand from more efficient cook stoves. The result was that charcoal prices fell significantly as the use of these cook stoves expanded meaning that households were able to afford to purchase more charcoal for cooking.

From its definition, it is clear that the direct rebound effect for consumers is closely linked to the concept of the price elasticity of demand for energy. The own-price elasticity of demand (the change in demand for an energy service in response to a change in its price) is essentially equivalent to the negative of the rebound effect[8]. An own-price elasticity of demand for biomass, for example, of -0.40 would imply that a 10% fall in the volume of biomass required to deliver a given energy service (e.g. cooking) which leads to a 10% fall in the cost of this service would only deliver a 6% fall in consumption[9]. The rebound effect, therefore, would be 40% in this case.

For producers, direct rebound effects are related to a fall in the marginal cost of production brought about by an energy improvement. When the marginal cost of supplying one particular product falls, this enables the production of larger quantities for the same total cost.

A listing of factors that can impact on price elasticities of demand (and, therefore, direct rebound effects) is shown in Box 2.There are a number of reasons to expect these effects to be higher in lower-income countries. For example, consumers in the developing world do not typically use just a single energy type for heating or cooking purposes, as is more typically the case in developed countries. That increases their ability to shift between fuels as relative prices change. Consumers in developing countries likewise typically spend a greater proportion of their income on energy, which means their demand is likely to be more sensitive to price.

Box 2 Factors affecting price elasticities of energy demand (and direct rebound effects)

- Percentage of income spent on the good or service: the higher the percentage of the consumer's income that the product's price represents, the higher the elasticity, all else equal
- Availability of substitute goods: the more and closer the substitutes available, the higher the elasticity is likely to be
- Necessity: the more necessary a good is, the lower the elasticity
- Duration: for most goods, the longer a price change holds, the higher the elasticity is likely to be, (more time and reason to search for substitutes)
- Cultural habits/brand loyalty: the greater the attachment to a certain brand or cultural

8 The two are not strictly equivalent. The magnitude of responses may differ if capital expenditures are required to realise part of the rebound effect, which will reduce the size of this effect relative to the elasticity estimate. The rebound effect is also calculated with respect to consumption of an energy service (e.g. lighting) whereas elasticity estimates are calculated with respect to consumption of an energy type (e.g. electricity).

9 The 10% fall in cost leads to a 4% increase in consumption (-10% x -0.40).

tradition, the lower the demand elasticity

- Who pays: where the consumer does not directly pay for the good, demand is likely to have a lower elasticity
- The cost of switching between products: the greater the cost of switching, the more likely is demand to have a low elasticity
- Peak and off-peak demand: demand has a low elasticity at peak times and a higher elasticity at off-peak times

Improvements in energy efficiency may also relieve constraints on energy availability which, in turn, can allow the meeting of suppressed demand which was previously unserved. This is likely to be a much more significant impact in lower-income countries where supplies are often inadequate to meet all demand willing to pay its cost.

The extent to which demand is saturated will also play a role. Where consumers already have and use a full range of energy-consuming appliances they may not increase demand much even if prices fall (there is a limit on how much more television one can watch!). But this may well not be the case in lower-income countries.

Indirect rebound effect

Whereas a direct rebound effect drives an increase in demand from the same energy user for the same energy type or energy service following an energy efficiency improvement, there are a number of indirect effects that also arise following an energy efficiency improvement. The first effect concerns the energy utilized to produce the intervention itself, such as the energy utilized to manufacture a CFL or improved cookstove. This is referred to as the **"embodied" energy effect**. This effect can be expected to be smaller in the long-term than in the short-term. The embodied energy associated with the production of the efficiency improvement is analogous to a capital cost whose importance diminishes relative to the ongoing energy savings as the lifetime of the investment increases.

The extent to which the embodied energy effect will be larger or smaller in the developing world relative to the developed world will depend greatly on the actual intervention. For CFLs, whose production is likely to be more global in nature, embodied energy will be the same no matter the final user. However, for certain interventions, it will be important to consider the specific manufacturing process as this may differ between regions for reasons such as different relative input (labour, capital and energy) prices, different levels of access to modern technologies, legacy investments (such as outdated energy-inefficient equipment) and different qualities of raw materials (changing the extent of processing required).

In addition to the energy required to produce and install the given intervention, consideration must also be given to the additional energy demanded from an increase in demand for other goods and services, or the **re-spending/re-investment effect**. For example, fuel savings from an improved biomass cookstove may not only be utilized for additional biomass, but may also be utilized for additional hours of lighting or for a new appliance such as an electric iron. On the production side, net energy savings from efficiency improvements (after direct rebound effects) may be used to increase output of one or more of their products. In addition to increasing demand for energy inputs, demand for other production inputs (capital, labor, materials) will rise, and each in turn requires energy to produce or support as well, leading to further indirect rebound in energy demand. (Jenkins, Nordhaus and Shellenberger, 2011).

There is an inverse relationship between the direct and the indirect rebound effect. The greater the proportion of savings spent on the more efficient energy service (the direct effect) then the smaller the remaining savings to spend on other goods and services. Initially, then, the supposition might be that the re-spending effect would be smaller in developing countries than in developed countries given we expect a higher direct effect in lower-income countries. However, the available literature suggests that this may be offset by a higher share of energy in marginal consumption spending in developing countries (ie, goods and services purchased out of re-spending have a higher energy content in developing countries than in developed countries). This might be the case, for example, where there is a large and previously unmet demand for energy-using appliances which is more likely in developing than developed countries.

Economy-wide rebound effect

The economy-wide effect is defined in the literature in different ways. Some authors define it as the sum of the direct and indirect rebound effects. However, others (for example, Barker et al. (2009)) define a 'macroeconomic rebound' effect comprising the indirect and economy-wide rebound effects, implying that they consider the economy-wide effect to be something additional to the direct and indirect rebound effects. For practical purposes, given that it is effectively impossible to estimate all indirect rebound effects and, thereby, to capture and sum all of these, the choice of definition makes little difference. A practical definition would be that the direct and indirect rebound effects are generally estimated on a 'bottom-up' basis looking at changes in consumption patterns of individual consumers whilst the economy-wide rebound effect is estimated on a 'top-down basis' looking at the total change in energy consumption without seeking to decompose this.

Setting aside the issue of how the micro-economic direct and indirect effects link with the broader macro-effects, three separate effects can be considered within this rubric: price, composition and economic growth.

Beginning first with the **price effect**, if energy efficiency improvements reach across a significant enough number of consumers, decreases in demand for a given fuel at the consumer level could combine to cause a perceivable decrease in demand at the level of the market (or economy) as a whole. This, in turn, could cause the market price for the fuel to decrease which, in turn, would cause the demand for the fuel to increase for all consumers and not just those benefitting from the energy efficiency intervention.

Theoretically, the scale of the market price effect will be proportionate to the responsiveness of aggregate energy markets to changes in the price of energy services and fuels, including both the aggregate own-price elasticity of demand (as energy users increase consumption of energy services in response to falling prices) and the elasticity of substitution (as now-cheaper energy services substitute for other consumer products and services or production inputs). Given the elasticity of demand for energy and energy services is greater in developing countries than in developed countries, the likelihood of market price rebound effects, given sufficient scale in energy efficiency improvements, is likely to be higher than in developed countries, although, again, the probability will depend greatly on the underlying market dynamics.

In considering market price effects, consideration should also be given to how well the market for the fuel functions. The example of the rebound effect from introducing improved cook stoves in the Sudan, resulting from rigidities in the supply chain for charcoal and, therefore, a failure of prices to respond to changing demand for charcoal, has been given in Box 1. Similar rigidities in fuel supply chains are likely to exist in many developing countries, particularly for traditional fuels.

It is worth noting that market-price induced rebound is likely to be greater in the longer-term than in the short-term given the time it will take for the direct effects to work their way through to the market. The same is particularly true for producers given substitution is constrained by capital turnover.

The second macroeconomic effect concerns **changes in the composition of the economy**. Given energy efficiency interventions improve energy productivity whilst decreasing the implicit price of energy, energy intensive goods and services correspondingly will lower in price. This will cause demand for energy-intensive goods to increase, leading to a corresponding shift in the composition of the economy towards energy-intensive sectors and a corresponding rebound in demand for energy and energy consumption. (Sorrell, 2009) The composition effect can be considered analogous to the substitution component of the direct rebound effect.

How all of the other individual effects come together to impact the overall economy and thus demand in energy is captured by the final macroeconomic rebound effect, known simply as **economic growth effects**. As energy efficiency improvements increase real incomes on a consumer level due to the implicit decrease in the cost of the fuel, consumers will purchase additional goods, services and/or re-invest the savings. If sufficiently widespread, these expenditures will stimulate economic growth. As the economy grows, demand for goods and services will correspondingly grow and these goods and services will, in most circumstances, result in a further rebound in energy consumption. (Sorrell and Dimitropoulos, 2007; Sorrell, 2009)

Additionally, improvements to energy efficiency on a consumer level will combine to realize an increase in the energy productivity of the economy. This increase in the overall energy productivity, all else equal, will lead to an increase in the economic output of the country.

The magnitude of this effect will be relative to the role energy consumption plays in economic growth. One might surmise, then, that rebounds from economic growth might be larger in developed countries relative to developing countries given the higher levels of energy consumption in developed countries. However, in developing countries, while average energy consumption is lower than in developed countries, the change in economic growth in response to a change in energy supply may well be higher. Such increasing returns to scale would typically result where constraints on the supply of or demand for energy services previously prevented these reaching desired levels. As an example of this, in countries where reliance on locally-collected wood and other biomass is high, increases in energy efficiency such as the introduction of improved cookstoves reduce the time and labour required for collecting fuels. This frees up resources for income-generating activities, such as home industries, and for education which delivers longer-term improvements in economic growth. In economics terms, the improved cookstoves have relaxed a supply constraint (the requirement to collect fuel), allowing the marginal cost of energy provision to fall

SECTION 3

How large is the rebound effect?

Review of the literature

There is an extensive literature estimating the rebound effect. A total of 163 academic papers and other published studies containing a total of 241 different reported estimates of the magnitude of rebound effects were reviewed in the preparation of this report.

These estimates are heavily concentrated in high-income countries, notably the USA and the UK. A summary of the geographic coverage of those studies that do provide estimates for individual countries is shown below. The number of countries represented is actually less than this might suggest as, in many regions, estimates are only available for one or two countries. For example, of 13 estimates for the Sub-Saharan Africa region, over half (seven estimates) are for South Africa. Even where multiple studies are available for a single country, these are often by the same author using the same data base in different papers. For example, although 19 studies have been identified for China, two authors are responsible for nine of these.

Country group[10]	Country / region	Number of studies
High-income	USA	40
	UK	31
	Other high-income	43
Middle and low-income	Europe and Central Asia	12
	Sub-Saharan Africa	13
	Middle East and North Africa	0
	South Asia	13
	China	19
	Other East and South-East Asia	5
	Latin American and the Caribbean	19

Table 3 Geographic coverage of literature on rebound effects

The available estimates concentrate on the direct and economy-wide rebound effects. There are relatively few studies on the indirect rebound effect[11]—presumably because of the difficulties in both defining the boundaries of this effect and in estimating it. With respect to the latter, as the indirect effect is most commonly defined as the increase in the consumption of *other* goods and services which require energy, there are naturally inherent difficulties in establishing which other goods and services consumers choose to consume more of, and whether the increase in the consumption of such goods and services is actually a consequence of an increase in the energy efficiency of the good or service in question and not for other reasons. In other words, is the increased consumption of a particular good or service actually due to an indirect rebound effect? With respect to the methodology used to measure the rebound effect, Chitnis et al. (2013) point out that most studies measure income effects but fail to measure substitution effects which are key to estimating the indirect effect.

10 As defined by DFID.

11 Sorrell (2007) makes reference to the lack of studies on the indirect effect.

For those studies estimating direct effects, there is a focus on residential use followed by transport use. Only a small number of studies appear to look at the rebound effect in industrial uses.

Sector	Rebound effect type	Number of studies
Residential	Direct	62
	Indirect	12
Industrial	Direct	9
	Indirect	3
Transport	Direct	36
	Indirect	2
Economy-wide	--	93

Table 4 Sector coverage of literature on rebound effects

The quality of these estimates is, inevitably, very varied. We have assessed the strength of the evidence presented by the different studies and allocated them to four categories:

- ***High-quality:*** These are studies which have been published in peer-reviewed journals and which have received a large number of citations.
- ***Moderate-quality:*** These are studies which have received a moderate to high number of citations but may not have been published in peer-reviewed journals.
- ***Low-quality:*** These are studies which are not published in peer-reviewed journals.
- ***Not reviewed:*** These are studies which are either reporting estimates from other studies which have been reviewed or where no information on the methodology applied and samples used is provided meaning no assessment is possible.

The number of estimates meeting the requirements to be classified as high or moderate-quality is a small part of the total, as shown below. A large number of the studies reviewed were found to either not be based on new research or to be more in the nature of opinion pieces, with no basis for assessing the strength of the evidence provided.

Quality		**Strength of evidence**		
		High	**Moderate**	**Low**
Total		**84**	**15**	**13**
Country group	High-income	71	14	7
	Middle and low-income	13	1	6
Sector	Residential	34	5	0
	Industrial	9	0	0
	Transport	12	8	0
Type of effect	Direct	43	13	0
	Indirect	12	0	0
	Economy-wide	29	2	13

Table 5 Breakdown of literature by strength of evidence

Given the small numbers of studies in middle and lower-income countries and non-residential uses classed as high or moderate quality, we have avoided the creation of too many sub-categories when reporting values of estimates. Instead, we have limited ourselves to the following:

Two country groupings (defined using DFID's classification of countries):

- High-income countries (HICs)
- Middle and low-income countries (MICs and LICs)

Four uses:

- Residential: Space Heating.
- Residential: Other
- Industrial and Commercial
- Transport[12]

We have drawn a distinction between residential space heating and other energy uses for three reasons. Firstly, all our estimates for the rebound effect come from high-income countries and, therefore, using these to assess the magnitude of the effect in middle and low-income countries may be misleading. Secondly, the vast majority of ICF priority countries are located in tropical and dry climates where space heating requirements are limited. Thirdly, measures to improve the efficiency of space heating, such as better insulation, are not readily transferable to other energy uses such as appliance replacement.

The resulting matrix of estimated rebound effect magnitudes is presented below. The number of unique estimates of high and moderate quality in each cell is shown to provide an indication of the size of the database from which these estimates are drawn. Most notably, for middle and low-income countries only estimates of residential (non-space heating) direct rebound effects have more than one or two estimates available. For all countries, there are few estimates of indirect effects other than for residential (non-space heating) uses in high-income countries.

Country group	*Number of studies (high / moderate quality)*		**Residential - Heating**	**Residential - Other**	**Industrial and Commercial**	**Transport**
	High Income	**Direct**	**6 / 2**	**14 / 3**	**6 / 0**	**10 / 8**
		Indirect	**1 / 0**	**6 / 0**	**2 / 0**	**1 / 0**
		Economy-wide	**0 / 0**	**7 / 0**	**13 / 1**	**5 / 0**
	Middle + Low Income	**Direct**	**0 / 0**	**5 / 0**	**1 / 0**	**1 / 0**
		Indirect	**0 / 0**	**2 / 0**	**0 / 0**	**0 / 0**
		Economy-wide	**0**	**2 / 0**	**1 / 1**	**1 / 0**

Table 6 Rebound effects estimates matrix

A more detailed discussion of the literature including the main methodologies used is provided in Appendix A.

Direct rebound effect

Estimates of the size of the direct rebound effect obtained from the literature are shown in Table 7 and presented graphically in Figure 2. The 'central range' reported in the matrix is

12 Estimates for rebound effects in transport are included for information. Transport is not the focus of this paper and the estimates of rebound effect in this use are not discussed or reviewed in the text.

for the 25th to 75th percentile, where sufficient numbers of estimates are available to make reporting such a range meaningful. The lines shown in the chart show the full range of estimates. Both the median and mean are shown. Our preferred measure is the median to avoid the average being skewed by outlier estimates. Where studies report a range of estimates, the range is used in determining the central range in Table 7 and the end-points of the range are shown in Figure 2. For the purposes of calculating the median and mean, the mid-point of the estimated range in the study is used.

Only values from those studies assessed as high quality are shown below. A comparable matrix using both high quality and moderate quality studies is shown in Appendix A. The addition of moderate quality studies does not change the values shown significantly except for the estimated direct rebound effects in transport in high-income countries. This is to be expected given the small number of estimates classed as being of moderate quality, except for this category (refer to Table 6 , above). The same holds even if the studies included are expanded to incorporate those assessed as being of low quality.

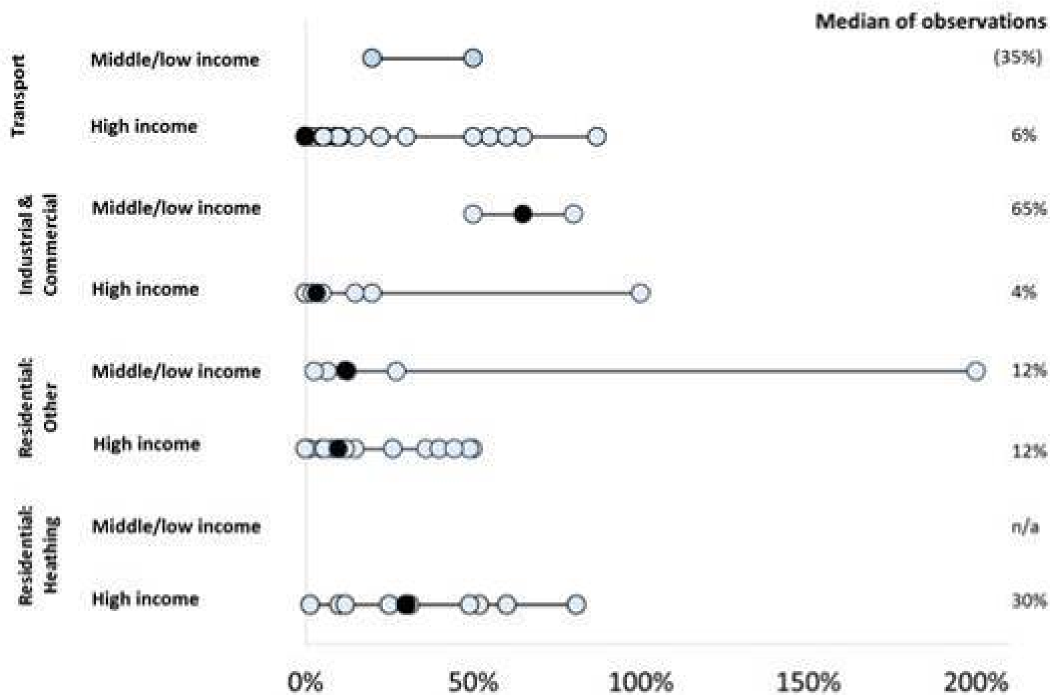
			Residential – Heating		Residential - Other		Industrial and Commercial		Transport	
Country group	***High Income***	**Central range**[13]	**19%**	**51%**	**7%**	**37%**	**0%**	**19%**	**0%**	**20%**
		Median	**30%**		**12%**		**4%**		**6%**	
		Mean	**35%**		**20%**		**16%**		**16%**	
	Middle + Low Income	**Central range**	***no data***		**8%**	**23%**	**58%**	**73%**	**28%**	**43%**
		Median			**12%**		**65%**		**35%**	
		Mean			**44%**		**65%**		**35%**	

Table 7 Direct rebound effect estimates (*high quality* studies)

In the figure below, each dot represents an estimate for direct rebound effects within each of the categories and country-groups specified on the y-axis. The right hand column and dark dots in the diagram represents the median value of the observation in each category and country.

13 The central range is that between the 25th and 75th percentiles.

Figure 2 Direct rebound effect estimates



The available evidence suggests the following:

- Direct rebound effects in residential uses other than space heating fall in a range of around 10% to 30%. This is reasonably consistent across high-income and middle and low-income countries.
- Direct rebound effects in residential space heating are rather higher at 20% to 50% (estimates only available for high-income countries).
- Direct rebound effects in industrial and commercial use are somewhat lower than in residential uses, falling in a range from 0% to 20%. There are theoretical reasons to believe these effects may be higher in middle and low-income countries (as discussed elsewhere in this paper). However, there are insufficient observations available to draw any firm conclusions on this point from the quantitative data (the estimates shown are for a single study in India).

A lower direct rebound effect in industrial and commercial uses would make intuitive sense. Energy consumption in these uses is driven by demand for the product or service provided. If this demand for the firm's output is relatively inelastic with respect to the energy cost then the direct rebound effect will be limited and, instead, the energy savings will translate into higher profit margins[14]. By contrast, energy consumption by households is largely a function of the decisions taken by that household itself.

As a check on these estimates, we have reviewed them against a number of estimates of own-price elasticities of energy and electricity demand. As discussed in section 2, these can be assumed to approximate the inverse of the assumed rebound effect.

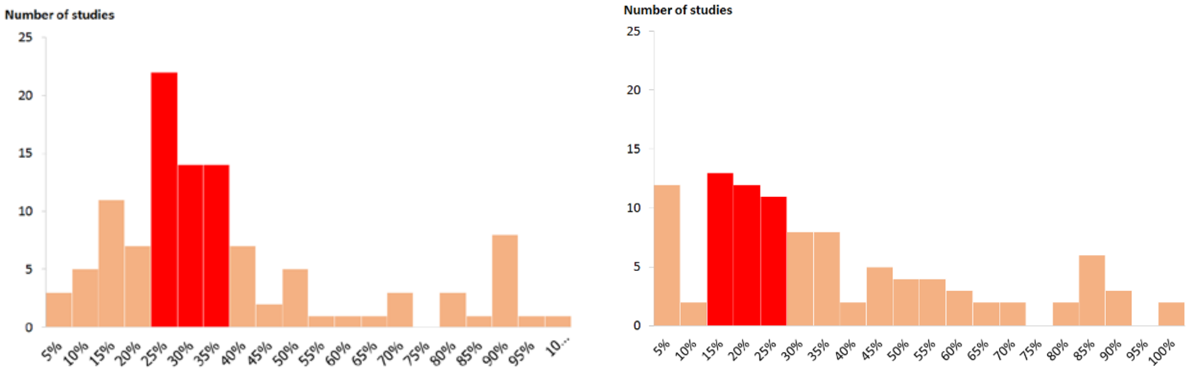
14 This assumes an individual firms makes the savings. If all firms in a competitive sector make similar energy efficiency savings then the result will be to simply maintain profit margins but to reduce the price to consumers of the output produced using this energy.

In Figure 3, below, the charts show the number of studies with an implied direct rebound effect falling into each of the bands along the y-axis. These show that estimates from these elasticity studies cluster around a direct rebound effect of 25-35% for energy demand and 15-25% for electricity demand. This would support the range derived from a literature review for direct rebound effects of 10% to 30%.

Figure 3 Elasticity studies by estimated direct rebound effect (all countries)

Energy demand direct rebound effect

Electricity demand direct rebound effect



Indirect rebound effect

Estimates of the magnitude of indirect rebound effects are shown in Table 8 and Figure 4. These are drawn from a much smaller number of studies than the estimates of direct rebound effects and should be treated with great caution.

			Residential - Heating	Residential - Other	Industrial and Commercial	Transport
Country group	***High Income***	**Central range**	**16% 45%**	**1% 9%**	**15% 22%**	**6% 47%**
		Median	**31%**	**6%**	**18%**	**6%**
		Mean	**31%**	**10%**	**18%**	**33%**
	Middle + Low Income	**Central range**	***no data***	**44% 65%**	***no data***	***no data***
		Median		**50%**		
		Mean		**56%**		

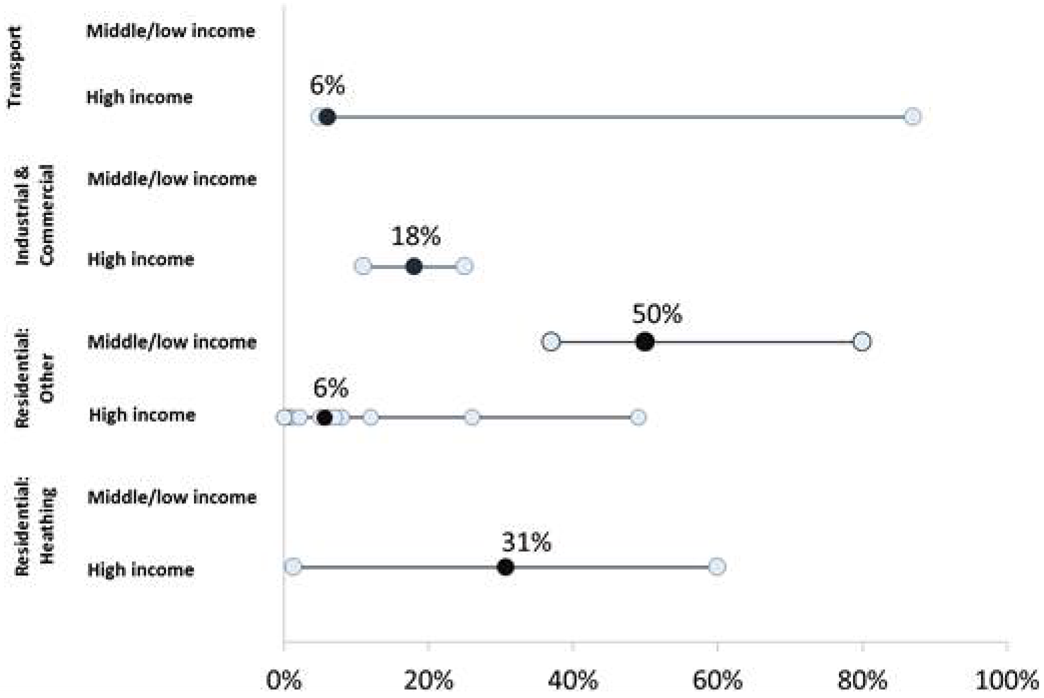
Table 8 Indirect rebound effect estimates (*high quality* studies)

Given the paucity of observations in other categories, only those shown for indirect rebound effects in residential (non-space heating) uses should be considered to be even minimally reliable. These suggest a range for indirect rebound effects of 0% to 10% in high-income countries, which might be noticeably higher in middle and low-income countries (although this conclusion is tenuous, being drawn from only two studies).

As discussed in section 2, a higher indirect rebound effect in lower-income countries would make intuitive sense. Behavioural economics and the corresponding literature suggest that the rebound effect, for a given intervention, will differ between income levels, whether this is between households in the same country or between households in a developed country and a developing country.

A key reason underlying this difference is the level of demand saturation. Generally speaking, the higher the income level of a consumer, the higher the level of consumption of a good and the greater the likelihood of demand being saturated.[15] Correspondingly, if demand is close to saturation, a consumer is less likely to use any extra income on a good. The effect on the magnitude of the rebound effect is thus such that the lower the income of a consumer, the higher the expected direct rebound effect. This can be carried through to the indirect rebound effect with consumers with very low incomes, being the furthest from demand saturation, being in the position where they are now able to purchase a good that was previously unaffordable. The indirect rebound effect is thus likely also to be much larger for lower income households or household in developing countries than in higher income households or in developed countries.

Figure 4 Indirect rebound effect estimates



Economy-wide rebound effect

Table 9 and Figure 5 show estimates for the economy-wide rebound effect. This includes both studies that have estimated this as the sum of direct and indirect effects and those that have adopted a 'top-down' approach, depending on the definitions of the rebound effects used by the author.

The number of studies estimating economy-wide effects is much larger than for those looking at indirect effects and their results vary very widely, with some estimating the rebound effect to exceed 100% ("back-fire").

	Residential - Heating	Residential - Other	Industrial and Commercial	Transport

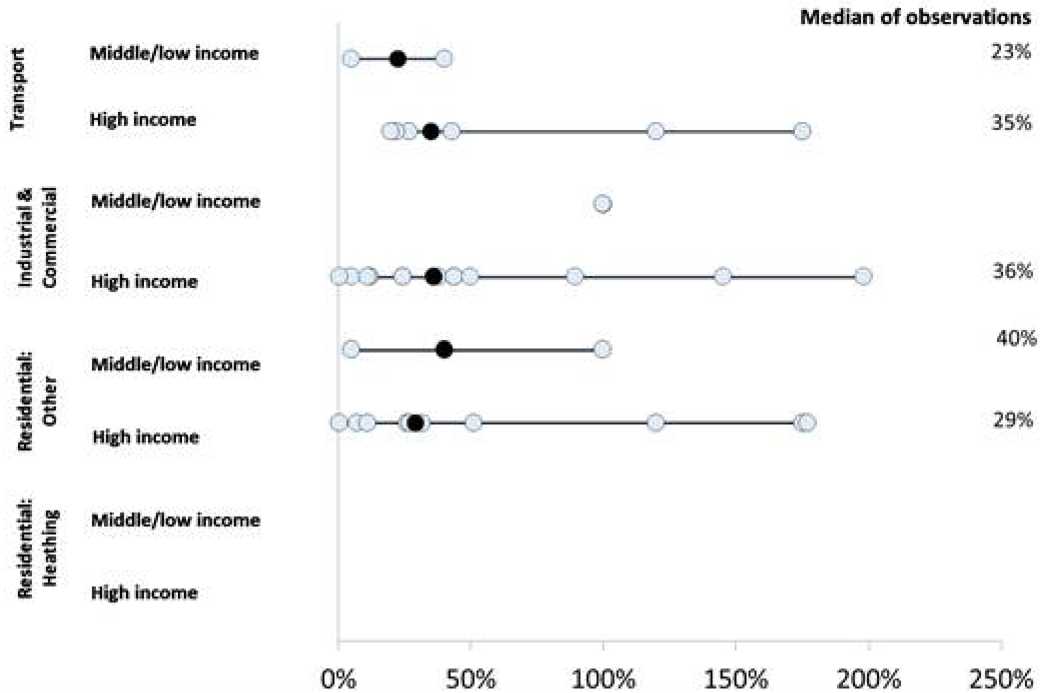
15 Sorrel (2007), Boardman and Milne (2000)

Country group	*High Income*	Central range	no data	15% 103%	12% 44%	23% 101%
		Median		29%	36%	35%
		Mean		63%	42%	68%
	Middle + Low Income	Central range	no data	23% 70%	100% 100%	14% 31%
		Median		40%	100%	23%
		Mean		48%	100%	23%

Table 9 Economy-wide rebound effect estimates (*high quality* studies)

Significant numbers of estimates are only available for residential and industrial uses in high-income countries. These would support a range for the economy-wide rebound effect from around 30% to 40%, although some estimates are much higher than this. Such a range would be consistent with the estimates for direct and indirect effects which suggest that, in residential uses (excluding space heating) these sum to 20% to 40% in high-income countries.

Figure 5 Range of Economy-wide effects across literature



Proposed ranges for rebound effects magnitudes

From the above review of literature, the following proposed ranges for estimates of the rebound effect to be used in options analysis have been derived. These ranges are inevitably somewhat subjective but represent a considered judgement of what is a reasonable value based on the limited available evidence.

	Residential - Heating	Residential - Other	Industrial and Commercial

Country group	*High Income*	Direct effect	20-40%	0-20%	0-20%
		Total / economy-wide effect	40-60%	10-30%	20-40%
	Middle + Low Income	Direct effect	--	10-30%	0-20%
		Total / economy-wide effect	--	30-50%	20-40%

Table 10 Proposed rebound effect ranges for project analysis

Indirect effects are not separately identified, but can be assumed to be the difference between the total or economy-wide effect and the direct effect. This is the approach taken by Sorrell (2007). For example, in the case of the rebound effect in the industrial and commercial sector in middle and low income countries, the total or economy-wide effect ranges between 20 and 40% while the direct effect lies between 0 and 20%. Accordingly, the indirect rebound effect for this category would also be between 0 and 20%.

We have not provided estimates for rebound effects in space heating in middle and low-income countries as there were no studies (of any quality classification) identified for this category.

Review of evidence for MICs and LICs

In this section we turn the focus on the evidence of the rebound effect for middle-income and lower-income countries (MICs and LICs respectively). Due to the low number of studies and estimates available among the literature reviewed, the analysis in this section incorporates evidence from studies of all qualities: Low, Moderate and High Quality as well as studies which are classified as Not Rated. The table below summarises the number of studies that fall under this classification for each category:

Number of studies (all qualities)			Residential - Heating	Residential - Other	Industrial and Commercial	Transport
Country group	*Middle + Low Income*	Direct	0	5	1	1
		Indirect	0	2	0	0
		Economy-wide	1	10	11	3

Table 11 Estimates matrix of rebound effects in MICs and LICs

In contrast to Table 6 in the previous section, the number of estimates that is available when assessing all literature is significantly larger for the economy-wide effect across all four categories. In the case of the other two effects, the number of studies remains the same. An important observation is that the studies that provide evidence on the rebound effect in MICs and LICs are based on a limited number of countries. Of the 34 studies identified, nine papers present evidence for China while Kenya and Sudan are represented by a further four studies each. These three countries alone, therefore, represent half of the studies reviewed.

Direct rebound effect in MICs and LICs

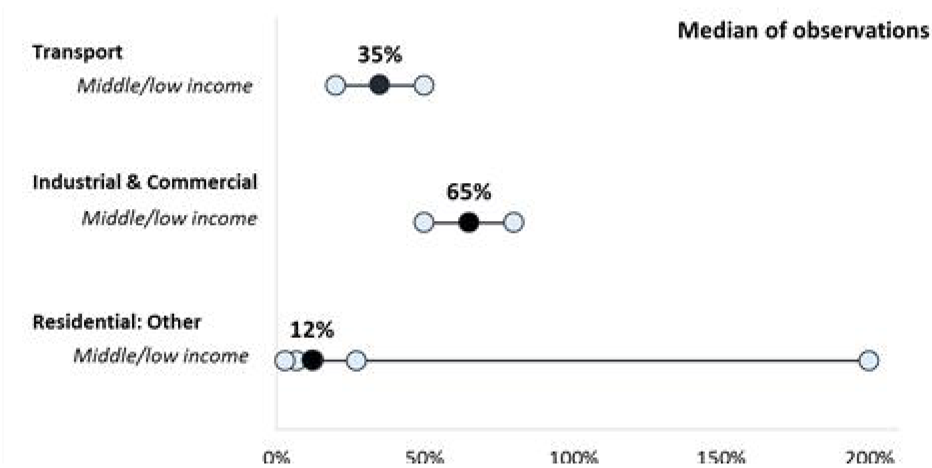
Table 7 presents the central range, median and mean for the direct effect obtained from all studies for MICs and LICs. In this case, there are no differences with the analysis carried out early focusing solely on high quality studies.

Direct effect			**Residential – Heating**	**Residential – Other**	**Industrial and Commercial**	**Transport**
Country group	***Middle & Lower-Income***	**Central range**	*no data*	**8% 23%**	**58% 73%**	**28% 43%**
		Median		**12%**	**65%**	**35%**
		Mean		**44%**	**65%**	**35%**

Table 12 Direct rebound effect estimates in MICs and LICs

The estimates for MICs and LICs are illustrated below:

Figure 6 Direct rebound effect estimates for MICs and LICs

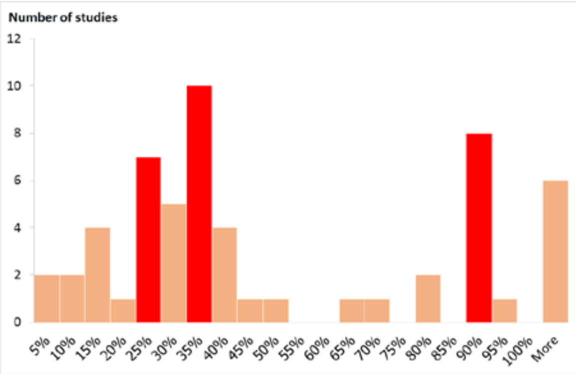


Because the evidence is the same, as above, this reinforces the earlier observation that in MICs and LICs, the direct effect is expected to be strongest for the industrial and commercial sectors than in the residential and transport sectors. Moreover, the direct effect for industrial and commercial activities is stronger than in HICs although we caution this is based on a single study for India.

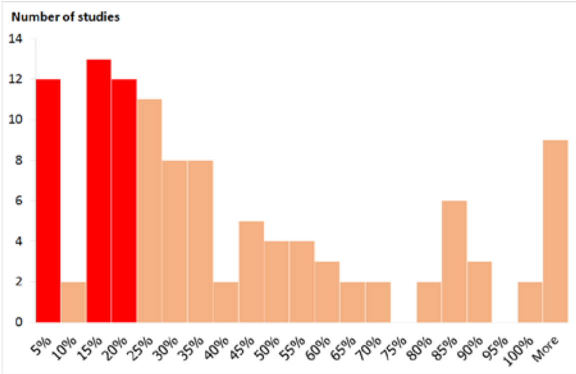
The histograms below show the evidence collected on the direct rebound effect for MICs and LICs from analysis of price elasticities of demand for energy and electricity demand. These suggest the effect is concentrated in the range from 15-35%, which is consistent with the estimates for all countries, but also that the magnitude of rebound effects is rather more dispersed for MICs and LICs than for HICs. This may be due to factors such as lower incomes in these countries or to the greater unreliability and smaller number of studies for these countries or a combination of these reasons.

Figure 7 Elasticity studies by estimated direct rebound effect (MICs and LICs only)

Energy demand direct rebound effect



Electricity demand direct rebound effect



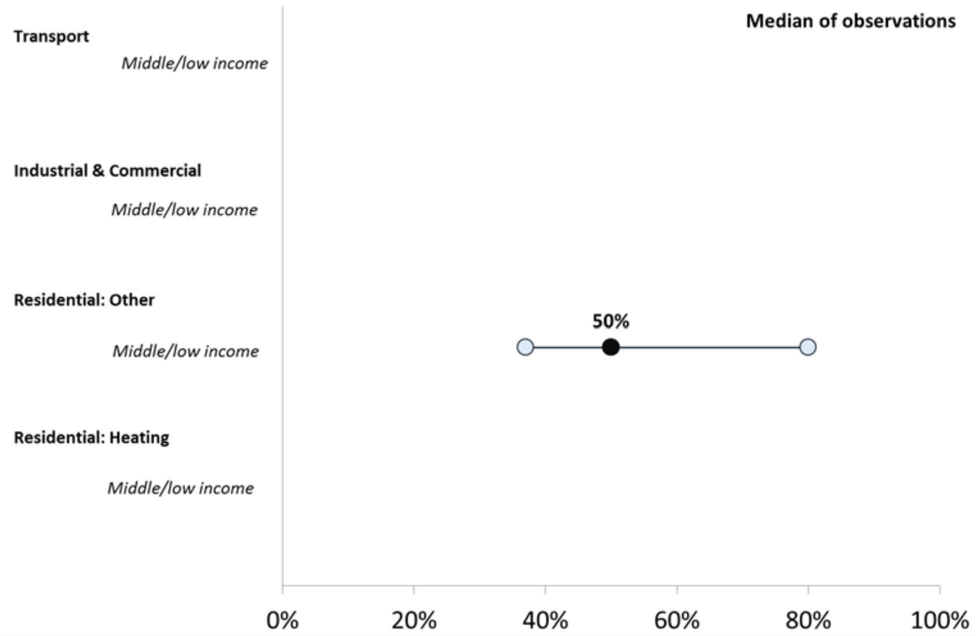
Indirect rebound effect in MICs and LICs

Table 13 summarises the estimates of the indirect rebound effect obtained from the literature. Also these figures remain as shown earlier. This is mostly due to the difficulty in measuring the indirect effect and consequent lack of studies.

Indirect effect			Residential – Heating	Residential - Other	Industrial and Commercial	Transport
Country group	*Middle & Lower-Income*	Central range	*no data*	44% 65%	*no data*	*no data*
		Median		50%		
		Mean		56%		

Table 13 Indirect rebound effect estimates in MICs and LICs

Figure 8 Indirect rebound effect estimates for MICs and LICs



Economy-wide rebound effect in MICs and LICs

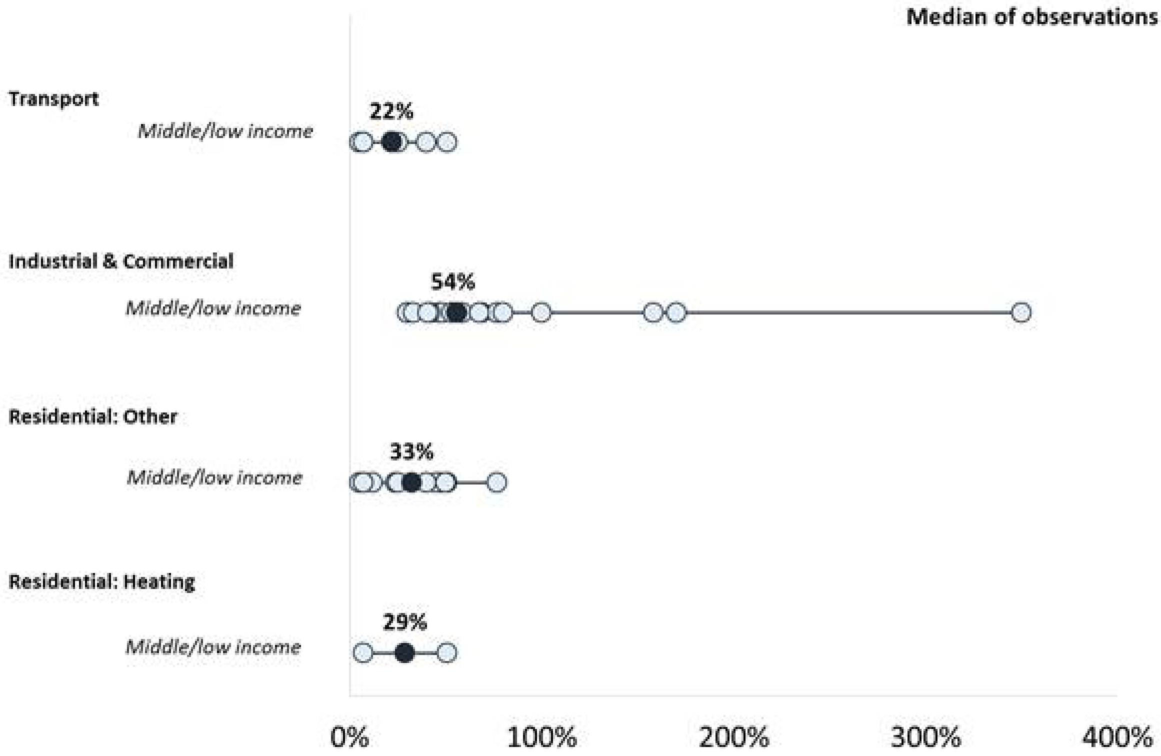
Finally, the largest difference is exhibited in the study of the economy-wide effect. When including all studies, regardless of their quality classification, the picture for MICs and LICs changes, but not significantly. Table 14 presents the ranges and other statistics to illustrate this.

Economy-wide effect			**Residential – Heating**	**Residential - Other**	**Industrial and Commercial**	**Transport**
Country group	***Middle & Lower-Income***	**Central range**	**18% 40%**	**20% 50%**	**45% 79%**	**7% 33%**
		Median	**29%**	**41%**	**56%**	**22%**
		Mean	**29%**	**41%**	**82%**	**22%**

Table 14 Economy-wide rebound effect estimates in MICs and LICs

The first noteworthy fact is that by including all studies, estimates for residential heating and transport are now available. The evidence suggests an economy-wide rebound effect of approximately 30 per cent for residential heating and approximately 20 per cent for transport. Other residential goods and services are still expected to exhibit an effect of the order of 40 per cent. The strongest effect is found for industrial and commercial activities which, in comparison to the previous analysis, have a median value of 56 per cent and a mean value of 82%. However, this high mean may well be distorted by the presence of three observations which appear to be outliers, with values of 158%, 170% and 350%. This can be seen in Figure 9.

Figure 9 Economy-wide rebound effect estimates for MICs and LICs



Note: The median values shown in the figure may differ from those in the preceding table. The figure shows the full range of reported estimates and the median derived from these. The table shows the central range (25th to 75% percentiles) where sufficient numbers of observations exist and the median derived from this range in order to remove the impact of outliers.

SECTION 4

Selecting a value for analysis

The proposed estimates in the preceding section are expressed as a range, with central ranges drawn from the 25th and 75th percentiles. However, for purposes of analysis, a single value will be needed.

As a default, we propose the mid-point of the central range is used as a starting point. A higher or lower value then this (i.e. moving towards the extremes of the range) should be based on a qualitative assessment of factors that might affect the magnitude of the rebound effect in a particular case.

A summary of the qualitative factors to be considered is provided below. At the end of this section, a checklist incorporating these factors is provided (in Table 15) which can be used as a basis for selecting an appropriate value for the rebound effect within the presented range.

The estimation of how the rebound effect will play out in reality is inevitably complex and difficult to reduce to a single number. As an illustration of this, Box 3 describes some of the surprises that emerged in a study looking at the potential for rebound effects from the introduction of solar water heaters (SWH) in South Africa.

Box 3 Rebound effects from solar water heaters in South Africa

The study (Davis, 2010) looked at a pilot project for SWH roll-outs among low income households in Zanemvula, South Africa. The authors were able to confirm the presence of a rebound effect—the substitution of solar for electrical heating of water did not lead to a commensurate reduction in electricity consumption. But the study also threw up some interesting associated impacts. For example, whilst the number of times households heated water reduced from 3.1 to 2.5 times per day (attributable to SWH being more efficient in retaining heat), there was an increase from 3% to 26% in the proportion of households using hot water to wash clothing. The proportion of households using hot water to wash dishes also increased. Households also reported that personal hygiene habits had improved, although there was no change in the proportion of households using hot water for bathing.

In addition to these direct rebound effects, indirect effects were also experienced through increased appliance ownership. But the use of hot water for cooking actually reduced. Households were reluctant to use hot water from SWHs for cooking and, in particular, for hot beverages, due to "the unfavourable smell, taste and colour of the water", with individuals also questioning the health impacts of consuming water that is heated and stored in plastic or fibreglass cylinders.

There was also an unexpected significant negative interaction between the size of the rebound effect and household size. Only larger households (with more than three members) saw any reduction in electricity consumption following the SWH installation whilst in smaller households (<3 members), electricity consumption actually increased.

Some of these results would not generally be expected when assessing the potential technical savings and rebound effects ex-ante. The results, therefore, provide a good illustration of the manifold uncertainties involved in any such assessment which even the best starting estimates cannot overcome.

Income level of consumers

The income levels of the affected group may be significantly higher or lower than those of the population (and, therefore, country) as a whole. Appropriate adjustments should be made for this.

Higher income levels reflect consumption that is closer to a demand saturation point. Consequently, a higher direct rebound effect should be observed at lower levels of income and consumption.[16] A number of studies have shown this effect through within-country analyses[17].

For the indirect (and, hence, total) rebound effect, the impact of income levels is less clear. The impact on demand for other energy intensive goods will largely depend on the level of saturation of other energy intensive goods and services. Hence, if the level of saturation of these is also high, as might be expected in high income households, the indirect rebound effect will be lower. Intuitively, for middle income households with demand and more importantly access to more energy intensive goods and services, the indirect effect might be higher. For low income consumers, who may face capital constraints in purchasing new appliances, the indirect effect might again be lower due to these constraints. As Davies (2010) notes, lower income households who cannot afford to acquire more energy-efficient appliances, may instead choose to use their existing appliances more efficiently.

As well as capital costs and demand saturation, income levels also have an impact on the opportunity costs of time used in increased consumption of energy services (e.g. watching television). Literature suggests that this will be closely linked to income levels. Greater income levels increase the value of time and opportunity cost of services where additional time is needed. This in turn reduces the rebound effect for these services.

Existing levels of energy efficiency / cost of energy services

The existing degree of efficiency (and therefore the actual cost of the energy service) also influences the level of the rebound effect. The level of efficiency acts as a proxy for the saturation of demand and income. The more efficient the existing energy service, the lower the direct rebound effect. For example, a consumer of an already energy efficient heater, may be consuming at a level close to their full demand and additional efficiency will only have a small impact on increased consumption[18]. The same argument applies to the cost of the energy service. If the cost is already at low levels, additional efficiency might not impact demand significantly.

Capital costs

A number of publications for rebound effects ignore the capital costs of purchasing new energy efficient systems and might therefore overestimate the rebound effects. High levels of capital expenditure needed to realise the savings reduces the funds available for increased energy consumption (assuming that borrowing against expectations of future savings is not possible). Conversely, the free provision of more energy efficient devices might lead to a higher rebound effect. One recent study[19] estimated the reduction in the

[16] Sorrel (2007), Boardman and Milne (2000)
[17] Madlener and Hauertmann (2011)
[18] UK Energy Research Centre, (2007)
[19] Chitnis, Sorrell, Druckman, Firth and Jackson. (2012).

‘true’ rebound effect resulting from the inclusion of capital costs in the calculation to lie between 5% and 60% depending on the technology. However this effect will reduce over time as consumers accumulate capital from ongoing savings in energy costs. For the purposes of project analysis, if higher capital costs are needed to realise energy savings then these can be assumed to reduce the rebound effect’s magnitude. However, offsetting this, will be that these higher capital costs may also reduce the initial level of savings below that expected as they will form a barrier to these savings being achieved. The combined impacts of a lower level of initial savings than might have been expected from engineering estimates, as a result of these higher capital costs, and a lower rebound effect, are ambiguous.

Who pays?
If the individual or entity paying for energy or an energy service is different from the user or consumer of the energy or energy service, then the rebound effect will likely be lower, all other factors being equal. This is because the consumer has no immediate reason to change behaviour. This is akin to the well-known principal-agent problem.

Energy cost to total cost/expenditures ratio
The greater the share of energy costs in total costs or expenditures, the greater will be the rebound effect. This is particularly true in the industrial sector where the improvement in competitiveness through energy efficiency and, therefore, the resulting increase in production, is expected to be greater the more important role is the role of energy as an input factor[20].

Availability of energy services
The availability to consume more of the energy service is also a key factor influencing the rebound effect. If access to the energy service is constrained due to a lack of electricity, the rebound effect will be smaller. Even with more energy efficient equipment, consumers may not be able to increase consumption as much as desired due to a lack of energy supply.

Market rigidities
Market rigidities which limit the ability of supply to respond to changes in demand may exacerbate the rebound effect. For example, as was described earlier, the introduction of improved biomass stoves into a rural area where supply was relatively fixed caused the market price of charcoal to drop as consumers no longer needed the same level for cooking and suppliers needed to rid themselves of their supply. The market price decreased which, in turn, increased demand.

Social and cultural norms
Social and cultural norms can determine the level of demand saturation and therefore influence the rebound effect. Existing studies [21] cite the example of changing American household laundry patterns over time as well as indoor temperature settings. These changes push the satiation point of demand further, leading to changes in the rebound effect. In developing countries, cultural norms are often closely tied with cooking habits, particularly stoves. Hence, efforts to introduce alternative means of cooking often met with less than full success.

While such norms are difficult to define, at least one study links the level of income inequality in a society to the size of the rebound effect. More unequal societies are likely to be more materialistic because inequality heightens status differences. This can lead to competitive consumption to increase individual status.[22] The direct and indirect rebound effect would

20 European Commission (2011)
21 Shove (2003)
22 ‘Wilkinson and Pickett, (2009)

therefore be higher among more unequal societies, as increases in disposable income are likely to be spent on more energy intensive goods, such as cars for example.

Checklist of qualitative factors

Table 15 provides a summary on the qualitative factors reviewed in this sub-section and their impact on the rebound effect. We use an illustrative classification of '+' (increases the RE) and '-' (reduces the RE) in the table to highlight the impact on the rebound effect based on anecdotal evidence from the literature research. Although the factors presented are not exhaustive, they represent the most prominent discussion points from the literature. This table can be used as a simple tool to categorise the rebound effect in the lower or upper range presented in the previous section.

Factors	Impact on direct rebound effect	Impact on indirect rebound effect
High income level of consumers	--	--
High existing efficiency of energy services	--	--
High existing true cost of the energy services	+	+
High capital costs associated with energy efficiency improvement incurred by the consumer	--	--
Separation between payee and user	--	--
Commercial sector compared to residential sector	--	--
Rigidities in markets	+	+
High energy to total cost ratio (industrial sector)	+	+
High availability of the energy service	+	--
High income inequality	+	+

Table 15 Qualitative factors and their impact on rebound effects

SECTION 5

How to include the rebound effect in analysis?

Including the rebound effect in options analysis

Our recommended approach is to select the mid-point of the relevant ranges shown in Table 16 (the derivation of which is described in the preceding section) as the base value. This should then be adjusted towards the upper or lower end of the range through a qualitative assessment using the checklist shown at the end of the preceding section.

Given the uncertainties involved in estimating the effect, an element of judgement is called for in determining an appropriate value. Recognising this, it is desirable for sensitivity analysis to be carried out to assess whether the conclusions reached change as the assumed value of the rebound effect changes. Appropriate values for sensitivity analysis might be the upper and lower bounds of the ranges shown.

In most instances, we recommend only incorporating the direct rebound effect into analysis. The values for the total or economy-wide effect are far more uncertain than those for the direct effect as is the time period over which this total effect will operate. Again, the impacts of limiting impacts to the direct rebound effect can be captured through the use of sensitivity analysis incorporating the total rebound effect, if desired.

We do not recommend attempting to estimate indirect rebound effects separately but to capture these, where considered to be important, through the application of the total rebound effect which can be interpreted as including both direct and indirect effects.

			Residential - Heating	Residential - Other	Industrial and Commercial
Country group	***High Income***	**Direct effect**	**20-40%**	**0-20%**	**0-20%**
		Total / economy-wide effect	**40-60%**	**10-30%**	**20-40%**
	Middle + Low Income	**Direct effect**	**--**	**10-30%**	**0-20%**
		Total / economy-wide effect	**--**	**30-50%**	**20-40%**

Table 16 Rebound effect ranges for analysis

The rebound effect and social welfare

It is important in any appraisal to recognise that the rebound effect is not an unmitigated negative from a social welfare perspective. To perceive it in this way will tend to skew the analysis and the conclusions reached from it.

The rebound effect comes about because the savings in energy costs and changes in relative prices resulting from energy efficiency interventions allow consumers to increase their consumption of energy services—whether this is through using existing appliances more intensively, purchasing new appliances or consuming other goods and services that require energy to provide. This represents a gain in welfare for these consumers—goods and services that were previously desired but could not be afforded can now be accessed.

At the same time, it is important in analysis to avoid double-counting of these welfare benefits. This additional welfare should already be captured by any estimates in monetary savings achieved through a reduction in energy consumption and there is no requirement for further adjustments to be made. To illustrate this, suppose a household is estimated to save US$ 1 due to an energy efficiency intervention, before applying any adjustment to estimated savings for the rebound effect. Household welfare can thus be assumed to have increased by US$ 1[23]. The same would hold if, instead, a rebound effect of 30% was applied. In this instance, the household would save US$ 0.7 in expenditures on energy services which is redirected to other uses, increasing its welfare by that amount. It would also be assumed to spend US$ 0.3 on consuming additional energy services. Assuming that the utility of these additional energy services is the same as that of the goods and services purchased using the remaining savings, then the household welfare has still increased by US$ 1 in total[24].

The wider benefits to society may well differ, of course, from the benefits to individual households and this may mean that the social welfare benefits of increased consumption of energy services differ from those of increased consumption of other goods and services. Practical constraints mean that these differences can only be assessed qualitatively. Even then, the impacts on social welfare of society as a whole are ambiguous. While increased consumption of energy services rather than of other goods and services may sound like a negative this may, for example, represent increased use of lighting to allow greater study time which increases the overall educational level of society. Or it may represent energy used for productive activities or to improve health or to increase access to information all of which also benefit wider society.

Applying the rebound effect in practice

Broadly speaking, the rebound effect should be incorporated into appraisals for three main types of intervention to reduce carbon emissions:

- Interventions directly focused on improving energy efficiency including appliance replacement.
- “Softer” interventions such as communication, awareness raising and support for new policies and regulations such as building codes.
- Interventions which are not directly targeted on improving energy efficiency but where rebound-like effects can be expected, such as switching from fossil fuels to renewable energy supplies.

23 This makes the simplifying assumption that the utility associated with the consumption of this extra dollar does not vary by the type of good; US$ 1 spent on additional energy services has the same impact on household welfare as expenditure of US$ 1 on any other good or service.

24 Strictly, in economic terms, this only holds if the retail tariff is equal to the marginal cost of energy. If the retail tariff is higher, then the rebound effect represents a welfare loss as the household’s procurement of additional energy, priced at the retail tariff, is less than it would desire if this energy was priced at the marginal cost of supply. The household is, therefore, under-consuming relative to its utility-maximising level. If the retail tariff is lower, then there is also a welfare loss as the household is consuming more energy through the rebound effect than would be the case if it had to pay the marginal cost of this energy, meaning resources in society are being diverted from more productive uses to supply this consumption.

Direct energy efficiency interventions

The first type of intervention identified above is those which directly act to improve the energy efficiency of a particular use or process. For example, this might involve the physical replacement of a relatively energy-inefficient appliance with one that is more efficient such as compact fluorescent lamps (CFLs) or improved cook stoves. It might also involve improvements in a physical process such as to reduce the energy required to provide a good or service.

Estimation of expected technical savings is relatively straightforward in such interventions, as is the application of a rebound effect adjustment. This can be applied directly to the estimated technical savings as described above. When assessing the wider social welfare impacts of the intervention, as discussed above, changes in household welfare should be based on the monetary value of the estimated technical energy savings in order to avoid double-counting.

"Softer" interventions

With regards to the second type of intervention—"softer" measures—it is more challenging both to estimate the technical savings and to assess the potential rebound effect. It is especially important in analysing such interventions to understand how the technical savings estimates were developed and the extent to which any rebound effect is already included in these.

An example of the practical inclusion of the rebound effect in options analysis is given below, in Box 4. This uses a business case prepared for a proposed energy efficiency intervention under DFID funding in South Africa. The intervention includes a number of elements but is particularly focused on awareness-raising. The options appraisal undertaken compared the net benefits of alternative options for the intervention. To do so, it estimated energy savings under the alternative options using the savings achieved for each pound spent by similar programmes in the United Kingdom.

The UK values used are based on ex-ante estimates of the technical savings from these programmes and, therefore, exclude the impacts of any rebound effect within the UK. The business case recognises this while noting that the magnitude of the rebound effect is very uncertain. While it does not explicitly adjust estimated energy savings for this effect, it does partially capture them by using a sensitivity that looks at the impacts of reducing the effectiveness of energy audits under the programme by 20%.

In the example, we illustrate how this analysis could be further developed using the rebound effect estimates presented in this report as an illustration of their application.

Box 4 Example business case for an energy efficiency programme in South Africa[25]

Background

The intervention was designed to support the private sector in South Africa to improve its energy efficiency. South Africa ranks 4th and 7th as the most carbon and energy-intensive countries out of the top 50 economies in the world. Analysis shows that industry lacks awareness of energy efficiency and capability to take action despite a context that, in many ways, is supportive of action on energy efficiency (rising electricity prices, pending carbon

25 The description and calculations described here are somewhat simplified from the original, in order to allow focus on how energy savings are incorporated into the appraisal and how the rebound effect could be captured.

tax, available finance). The intervention was targeted at the identified barriers of:

- lack of awareness of energy efficiency among industrial enterprises;
- lack of a capability within industry to identify opportunities for energy efficiency; and
- lack of capacity within companies to access available finance, and develop a business case for energy efficiency projects.

Options considered

Two main options for the proposed programme were identified. The first would provide remote advice and light-touch face-to-face services for small and medium-sized companies (SMEs) in any sector. By the second year, the programme would expect to be receiving enquiries from 3,000 companies and to have conducted 800 site surveys.

The second option would provide similar support but focused on the companies in the two to three most energy-intensive sectors and with a more structured engagement with the largest energy users within these sectors. By the second year, the programme would be offering remote advice to 1,500 companies, have conducted around 1,000 site surveys and be closely engaged with 63 large companies. This option would allow some reduction in total programme costs by reducing the numbers of companies involved.

The estimated costs of the two options are shown below.

Cost of alternative options

£m	Option 1 SMEs in all sectors	Option 2 Largest users in energy-intensive sectors
DFID funding		
Direct costs	5.2	4.8
Other costs	3.8	3.8
Programme total	**9.0**	**8.6**
Private investment	94.5	74.6
Total costs	**103.5**	**83.2**

Cost-Benefit Analysis

The cost-benefit analysis (CBA) conducted as part of the business case compares the monetary value of energy savings under the two options with the costs of each.

The key assumptions made in the business case are:

- Option 1 delivers lifetime savings in energy use of 0.4 MWh for every £1 spent, while Option 2 delivers savings of 0.46 MWh for every £1 spent.
- Energy savings are valued at the projected average cost of electricity in South Africa (from the 2011 Integrated Resource Plan) of £0.06/kWh.
- Carbon savings are estimated using a carbon intensity of 0.9 tCO_2/MWh.
- A social discount rate of 3.5% (following HMG Green Book guidance) is applied for carbon savings. Energy savings, which represent private benefits, are discounted at a rate of 10%, following common DFID practice.
- While the original business case did not include an assumed carbon value, we have applied one in this analysis. The value used is the central value of carbon in 2013 and 2014 used for public policy appraisal in the most recent update issued by the Department for Energy and Climate Change of £3.49/tCO_2e and £3.59/tCO_2e respectively[26].

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26 Updated Short-Term Traded Carbon Values Used for UK Public Policy Analysis, DECC, 16 September 2013.

The unit energy savings are estimated from assessments of the cost-effectiveness of the services delivered by the Carbon Trust in the UK. The latest available description of the methodology used for this purpose[27] states that, for services directly delivered by the Carbon Trust, energy savings are those anticipated once a survey is completed or action plan agreed. They, therefore, represent *ex ante* estimates of technical savings and do not explicitly incorporate any allowance for rebound effects.

The resulting CBA is summarized below. As can be seen, this suggests that while the benefits of either option exceed costs, Option 2 offers a higher net benefit and a more cost-effective means of reducing carbon emissions.

CBA of programme options

	Option 1	**Option 2**
Programme cost (£m)	9.0	8.6
Lifetime energy savings (GWh)	3,616	3,965
Lifetime carbon savings ($MtCO_2$)	3.3	3.6
Cost-effectiveness (£/tCO_2)	**2.8**	**2.4**
Discounted total cost (£m)		
Year 1	39.6	29.9
Year 2	58.4	48.8
Total	98.0	78.7
Discounted energy savings (£m)		
Year 1	74.4	76.0
Year 2	111.6	127.5
Total	186.1	203.5
Discounted carbon savings (£m)		
Year 1	4.3	4.4
Year 2	6.6	7.6
Total	10.9	12.0
Net Present Value (£m)	**99.0**	**136.8**
Benefit:Cost Ratio	**2.01**	**2.74**

Incorporating the rebound effect

The original business case recognizes the potential for a rebound effect but does not explicitly allow for it. Here, we set out how this effect might be incorporated into the analysis.

Our estimated range for the direct rebound effect in industrial and commercial uses of energy in MICs and LICs is 0-20% (see Table 16). The mid-point or base value is, therefore, 10%. There are a number of qualitative reasons to believe that the rebound effect for South Africa would be above this mid-point and towards the top end of the range. These include the low levels of energy efficiency at present, the rising cost of electricity, a high energy to total cost ratio and high availability of electricity (refer to Table 15). Therefore, we adopt an estimated value for the direct rebound effect of 15%. The estimated lifetime energy and carbon savings are reduced accordingly.

Consistent with the discussion earlier in this section on valuing social welfare, the welfare derived from the additional consumption of electricity under the rebound effect is assumed to be equal to that which would be derived from using the savings to consume other goods and services instead. The welfare reduction in reduced energy savings from the rebound effect is, therefore, assumed to be fully offset by the welfare benefit resulting from the

https://www.gov.uk/government/uploads/system/uploads/attachment_data/file/240095/short-term_traded_carbon_values_used_for_UK_policy_appraisal_2013_FINAL_URN.pdf

27 Carbon Trust Performance Assessment Methodology (http://www.carbontrust.com/media/169026/carbon-trust-performance-assesment-methodology.pdf)

corresponding increased electricity consumption. However, the value of carbon saving benefits does decline with the inclusion of the rebound effect, as there is no offsetting welfare gain.

We show below the results of incorporating this estimate of the rebound effect into the options appraisal. The effect is to suggest that, after allowing for the rebound effect, the two options are equal as regards the cost-effectiveness in reducing carbon emissions. The impacts of the rebound effect on the estimated NPV and benefit-cost ratio are relatively small given the value of carbon used in the analysis. Option 2 still has a higher net benefit than Option 1 implying it continues to be preferred.

CBA of programme options with direct rebound effects

	Option 1	**Option 2**
Programme cost (£m)	9.0	8.6
Lifetime energy savings with rebound effect (GWh)	3,074	2,931
Lifetime carbon savings ($MtCO_2$)	2.8	2.6
Cost-effectiveness (£/tCO_2)	**3.3**	**3.3**
Discounted total cost (£m)		
Year 1	39.6	29.9
Year 2	58.4	48.8
Total	98.0	78.7
Discounted energy savings (£m)		
Year 1	63.3	56.2
Year 2	104.4	103.7
Total	167.7	159.9
Discounted welfare gains from rebound (£m)		
Year 1	11.2	19.8
Year 2	7.3	23.8
Total	18.4	43.7
Discounted carbon savings (£m)		
Year 1	3.7	3.2
Year 2	5.6	5.6
Total	9.3	8.9
Net Present Value (£m)	**97.4**	**133.7**
Benefit:Cost Ratio	**1.99**	**2.70**

Interventions with rebound-like effects

The third type of intervention is those which are not targeting energy efficiency improvements but where a rebound-like effect can result. As a practical example, consider a project to implement off-grid small-scale renewables as a replacement for fossil fuels which, as well as reducing carbon emissions, is also expected to reduce the costs and increase the availability of electricity supplies (replacing diesel generation and kerosene lighting with solar panels, for example).

The reduction in the cost of electricity and increase in its supply can be expected to lead to increased demand for electricity following the intervention. This represents a combination of the income effect resulting from the reduced cost of electricity supply, the substitution effect resulting from the lower cost of electricity relative to other energy supplies and a demand effect from the removal of previous supply constraints. The outcome is that less fossil fuel generation will be displaced than might have been initially estimated. The increased demand might necessitate the retention of some fossil fuel generation to meet it and, therefore, reductions in GHG emissions following the intervention will be lower than expected. This is likely, as discussed above, to represent an increase in social welfare but it will lower the cost-effectiveness of the intervention in terms of reductions in carbon emissions. Alternatively, the new renewable energy sources could be oversized relative to engineering estimates of demand, to anticipate the impacts of the rebound effect, although this would obviously increase initial costs.

Values for the rebound effect can be used as a proxy to estimate the impacts of the lower cost of the new supplies on demand for electricity (or other energy types) which may increase this above expected levels and, therefore, require the retention of fossil fuel generation. However, as discussed earlier, such a use of the rebound effect can only approximate these impacts. The rebound effect represents the effect of providing the same single energy service or consumable (lighting, for example) at a different, lower price, which, in turn, shifts the relative prices of goods. However, in the example given of introducing renewable energy-based generation, this is changing the input price of an energy type (in this case, electricity), which then changes the prices of energy services and consumables supplied using that input type. The two effects are not, therefore, strictly equivalent.

Where there was suppressed demand, the additional supply also introduces new consumption options into the household[28]. Estimates of the rebound effect do not incorporate such impacts—by looking at how demand for an energy service that already exists responds to a change in its price they implicitly assume that all existing demand for the service at its current price is met.

Appropriate caution should, therefore, be applied in any such analysis where estimates of the rebound effect are used to value changes in demand resulting from fuel substitution and similar interventions. However, it may still be the case that estimates of the rebound effect represent the best available data for the purposes of analysis, particularly where there is no time or budget to conduct more detailed demand surveys in the geographic area of the proposed intervention.

[28] In theoretical terms, the slope of the consumption possibility frontier changes due to a change in the set of possible goods to be consumed.

Appendix A Literature Review

This Appendix provides more information on the methodologies used to estimate the rebound effect in the literature reviewed and our assessment of the strength of the evidence provided by the different studies. It also provides estimates for the rebound effect using both high and moderate-quality studies, to supplement those shown in in the main body of this paper which includes only studies rated as high-quality.

Overview of the literature

We collected a total of 91 documents, most of which are from academic sources, i.e. journal articles, some are reports by donor agencies and others are chapters in books. A comprehensive list of these resources including online links is available in Appendix B.

Most of these include a review of previous literature available as part of the background to the study. In the more recent studies, estimates of rebound effects are provided either for selected energy services or for the entire economy (economy-wide effects).

In addition, through the literature review of the abovementioned 91 documents, further estimates were gathered, raising the number of data sources to approximately 160.

Searches for the publications and papers were carried out on Google Scholar and ScienceDirect. In those cases for which papers were not publicly available, we purchased them through ScienceDirect.

Only two working papers by donor agencies which quantified the rebound effect were identified. We have followed-up with the authors of these papers who have advised us that these were one-off pieces of research and that, in general, data that can be used to estimate rebound effects is not collected as part of the monitoring and evaluation of projects funded by their agencies. Indeed, one of these papers (on the rebound effects associated with a CFL programme in Ethiopia) used customer billing data from the electricity utility under an informal and private agreement rather than data collected for project evaluation purposes.

We have also contacted energy sector specialists in a number of middle and low-income countries with whom we are familiar to ascertain whether they are aware of papers and research conducted in those countries. To date, none have been identified.

Quantifying the rebound effect

There is a variety of different methodologies applied to quantify the rebound effects. This sub-section focuses on the most widely applied and used in the literature of rebound effects.

Estimation methodologies

The various estimation methodologies used are summarised below and described in more detail below the table.

Methodology	Description	Type of rebound effect estimated
Direct relative measure	Relative difference between expected and actual savings realised.	Direct Indirect
Econometric techniques	Econometric elasticity estimations are used as proxy for direct and indirect rebound effect. It requires assumptions about demand, the most common being the almost ideal demand system (AIDS). The most common techniques employed are OLS, 2SLS and 3SLS estimations.	Direct (elasticities)

Methodology	Description	Type of rebound effect estimated
Life cycle analysis	Is used to calculate environmental rebound effects by measuring the environmental impact of EE improvements using life cycle analysis (LCA).	Indirect
Macro-economic models	Models of the economy which assume either endogenous productivity growth (which is affected by EE improvements) or exogenous technological change.	Economy-wide
Computable General Equilibrium models	Country-specific models which use economic data to simulate the evolution of the entire economy to a specific change, i.e. EE improvement.	Economy-wide
Hybrid models	Combination of techniques, e.g. econometric estimations based on assumed production functions, e.g. Cobb-Douglas.	Economy-wide

Table 17 Most common estimation methodologies found in the literature[29]

- **Direct relative measures**
- These are the most straightforward estimation techniques that can be applied for direct as well as indirect rebound effect estimation. This methodology requires survey data before and after a specific renewable energy or energy efficiency measure has been introduced in one particular region. The direct rebound effect can then be estimated on the basis of the following formula:
- $$Rebound\ effect = 100 \times \frac{technical\ savings - actual\ savings}{technical\ savings}$$

Besides a precise household survey or similar data set (e.g. billing records) before and after an energy saving measure was introduced, this methodology also requires an engineering estimate of the potential savings. Depending on the design of the household survey, indirect effects can also be estimated by tracking consumption of other energy services and goods.

Own price elasticities
These are widely used as proxies for the direct rebound effect. This is intuitive, as the elasticity captures the response in consumption of a service or good with changes in its price. Derived in detail in Gavankar et al (2011) the approximation of own price elasticities only applies under the following assumptions however:

- For this approach to be valid, the response of consumers to a change in energy prices must be the same as to a gain in efficiency. This might not necessarily be the case if high capital costs are required to achieve the efficiency gains. With high capital costs, responses to energy price changes will be higher (in absolute terms) than those for efficiency.
- Energy prices should not have an effect on energy efficiency, i.e. as prices changes energy efficiency remains constant. Again, this assumption might not hold true. Increases in energy prices and in particular oil prices have led to considerably more efficient appliances.
- Estimating own price elasticities requires robust demand estimations, which often requires large time series data-sets. Furthermore, the choice of demand models will also impact the results of elasticity estimations.

29 Based on Chakravarty et al. (2013)

Economic growth models and production functions
These are widely used to determine the economy-wide rebound effect. The major estimation parameter used for rebound effects is the economic input substitution factor across capital, labour, energy and other factors. Consequently, the results depend on the production function and growth model that is assumed. The traditional Cobb-Douglas production function used in the Solow growth model has been superseded by neoclassical growth literature and household production models.

Computable general equilibrium (CGE) models
These models are acknowledged as the most rigorous estimation method for the economy-wide rebound effects. CGE models use actual economic data to estimate how an economy might react to changes in policy, technology or other external factors. They numerically simulate the general equilibrium structure of the economy, which is characterised by a set of price and output levels across all sectors of the economy such that market demand equals supply in all the markets simultaneously. An approach such as CGE can be useful in the study of rebound because the technological improvements and policy decisions are likely to affect multiple sectors and economies. However the extensive data requirements for this type of model make it difficult to apply, in particular in a context of developing countries.

Other elasticity estimations
These can also be used for estimating the indirect effect. Although not found to be applied in any paper or publication, cross price elasticities or indeed income elasticities could in principle be used to estimate indirect rebound effects. The cross price elasticity of energy intensive goods and services (TV consumption in our example above) with respect to changes in the relative price of another energy services (lighting in our example above) would be an adequate measure for indirect effects. Similarly, income elasticities of other energy intensive services could be used. As the relative price of one service is reduced, disposable income increases and the income elasticity captures the impact on consumption of other services. The extensive data requirements associated with this estimation method are undoubtedly the main reason for a distinct lack of such estimation methodologies in the rebound effect literature.

Most commonly employed methodologies
The three different types of rebound effects, i.e. direct, indirect and economy-wide effects, are estimated in the literature using several of the methodologies described above.

The most straight forward measure used to estimate the direct and indirect rebound effects is a direct relative measure defined as the relative difference between expected or calculated savings for an energy efficiency improvement and the actual savings realised once the improvement has been carried out or implemented. Examples from the academic literature reviewed include Ouyang et al. (2009) who estimate the rebound effect for Chinese household energy efficiency solutions aimed at mitigating such effects. Chitnis et al. (2011) estimate direct and indirect rebound effects for six household measures aimed at reducing energy consumption in the UK.

Because the direct method has a high data requirement which is often difficult to obtain, other academics have used elasticity estimations as a proxy for estimating the rebound effect. Such estimations use different econometric techniques and require important assumptions about demand for energy services. The most commonly employed assumption is the almost ideal demand system (AIDS) which implies a linear demand function[30], e.g.

30 Demand functions are generally considered to be curved although, for small changes in demand, the impacts can be estimated using a straight-line demand line as a proxy (i.e. assuming the demand curve can be represented as a series of straight lines at changing angles).

Wang et al. (2012) estimate the elasticity of fuel consumption to study direct rebound effects for transport in China. Moreover, econometric techniques vary between papers, with the most common being ordinary least square, two least and three least squares estimations using panel data (Davis et al. (2012), Greene (2012), Small and Van Dender (2007), Madlener et al. (2005)). It is important to note that econometrically estimated rebound effects can be sensitive to the model specifications used, making them difficult to compare directly. Once elasticity is estimated, the rebound effect measure will vary depending on whether capital costs are accounted for.[31]

When estimating economy-wide rebound effects, three main methodologies are used. The most common involves utilising a computable general equilibrium models (CGE) which use economic data to simulate the evolution of the entire economy to a specific change for a given country. For instance, Washida (2004) use an applied CGE for the appraisal of environmental policies which incorporates 33 industrial sectors in Japan. Barker and Foxton (2008) to estimate UK economy-wide RE while Vikstrom (2008) studies the RE in Sweden.

A second method involves using macroeconomic models, most of which assume technological change to be endogenous, such as those employed in Goulder and Mathai (2000), Nordhaus (1999) and Goulder and Schneider (1999). In contrast, Azaar and Dowlatabadi (1999) used this method to model CO2 emissions employing an exogenous productivity growth rate assumption of 2-3%. Once more, this points to the results' sensitivity to model specifications and employed assumptions.

Thirdly, economy-wide rebound effects have also been estimated using hybrid models which employ econometric techniques as in Wei (2007) who estimates a Cobb-Douglas production function, Brännlund et al. (2007) who use econometrics to estimate a model assuming exogenous technological progress and Jorgenson (1998) who applies econometric methods to general equilibrium analysis.

There are two general points to be raised with regards to the methodologies used in the literature. First, different authors choose to estimate rebound effects in different terms, that is, although most estimations are based on the rebound effect based on energy consumption, other papers estimate such effect in terms of greenhouse gas emissions. Second, while some authors estimate rebound effects in both the short and long term, others only estimate them for one of the two time horizons. As is expected, estimates presented in the literature for the long term effect tend to be larger than those for the short term, and their ranges are usually broader as well.

In conclusion, the use of several methodologies in the estimation of the three different types of rebound effects, and the various assumptions employed affect the degree of comparability between estimates and thus lead to broad ranges derived from the available studies and evidence found in the literature. For this reason, it is important to develop a methodology to assess each country's and sectors likely position within a range to provide relevant estimates of rebound effects.

Limitations

Apart from the direct relative measure, which can only be applied for a small and specified consumer group, all methodologies above have severe limitations in their applicability. These limitations together with the lack of a commonly agreed on methodology largely explains the wide variety of estimation ranges across the literature. The main limitations of the estimation methodologies include:

[31] Chakravarty et al. (2013)

- ***Availability of data –*** Most methods require extensive data sets. These may be time series, panel data sets or project specific survey data. In most cases the data is difficult to obtain or not available, requiring the use of proxies or instrumental variables. This limitation is a particular difficulty in the estimation of rebound effects in developing countries, where data is less readily available.
- ***Statistical difficulties –*** Statistical inconsistencies can exist even if a suitable data set is found. Most notably these include: (i) the omitted variable bias: estimation methods often cannot take into account external factors such as weather, demographics or capital requirements for EE, making it difficult to isolate the rebound effect; (ii) the selection bias: If the analysis is based on survey, there is always a risk that only those households, who wish to participate in the survey are included, skewing the group of individuals forming part of the study.
- ***Own price elasticity estimates needed for one service –*** Elasticities can only be used for a well defined energy service. The own price elasticity of 'electricity demand' will be a combination of elasticities across different energy usages (e.g. lighting, heating, washing, etc...).
- ***Assumptions justifying own price elasticity as a proxy might not be valid –*** Two assumptions need to be satisfied for elasticity to be valid as a proxy for the direct rebound effect. As noted above, these might not be satisfied in reality.

Our approach to quality assessment

In assessing the quality of the individual estimates of the rebound effect, it is useful to rely on established methodology. This seeks to capture the rigour and trustworthiness of a study by evaluating its validity and reliability. In evaluating validity and reliability, there are a number of sub-concepts which can be considered, not all of which are relevant for this study. In identifying those which are relevant, identifying the extent to which individual estimates should be included in a composite indicator capable of acting as a rule of thumb in predicting potential rebound effects as part of a business case analysis was considered as the primary goal of the assessment. With this in mind, the following elements were identified as being important:

- ***External validity***: How generalizable is the result? Or, to what populations, settings, variables, etc, can the effect be generalized? Whilst a given estimate may be valid for a very narrow set of circumstances, for the purpose of rules of thumb, it is important that the estimate not be so narrow as to not apply to other situations. Thus, the more generalizable the result, the more weight that should be applied in including it in an average estimate. However, this does not mean the estimate should be disregarded completely as the underlying circumstances making the estimate ungeneralizable may still be interesting and may often provide lessons.
- ***Population validity*** (as part of an assessment of external validity): Does the sample populations represent the entire population? Is the sampling method acceptable?
- ***Internal validity***: How much confidence can be placed in the cause and effects? Could there be other variables not considered or are obvious variables ignored in the analysis?
- ***Construct validity***: Does the approach test the construct adequately?
- ***Face validity***: Does the project, "at face value" appear to be a good project? Does it appear to be robust?
- ***Reliability***: Do the differences between the underlying circumstances and variables seem to jive with the differences in the results? Why are there outliers? I suggest we treat reliability as a "single" assessment.

Although reliability and validity form the main part of any assessment of the quality of the indicators, conceptual framing, openness/transparency, and cogency should likewise be considered.

Obviously, such an assessment of each estimate of a rebound effect is not possible within the scope or timescale of this project. As an alternative, these same concepts are utilised to instead conduct an assessment of the sources.

High and Moderate quality study matrices

			Residential - Heating	Residential - Other	Industrial and Commercial	Transport
Country group	*High Income*	Range	12% 56%	7% 40%	0% 19%	9% 30%
		Median	30%	12%	4%	20%
		Mean	38%	23%	16%	25%
	Middle + Low Income	Range	*no data*	8% 23%	23% 58%	28% 43%
		Median		12%	65%	35%
		Mean		44%	65%	35%

Table 18 Direct rebound effect estimates (*high and moderate quality* studies)

			Residential - Heating	Residential - Other	Industrial and Commercial	Transport
Country group	*High Income*	Range	no data	15% 103%	15% 44%	23% 101%
		Median		29%	36%	35%
		Mean		63%	41%	68%
	Middle + Low Income	Range	no data	23% 70%	32% 67%	14% 31%
		Median		40%	33%	23%
		Mean		48%	54%	23%

Table 19 Economy-wide rebound effect estimates (*high and moderate quality* studies)

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