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Multiple Air Conditioners in Singapore Alley, 2003 (Permission under GNU Free Documentation License)

INTRODUCTION

The theme of this issue is the definition and quantification of the rebound effect.

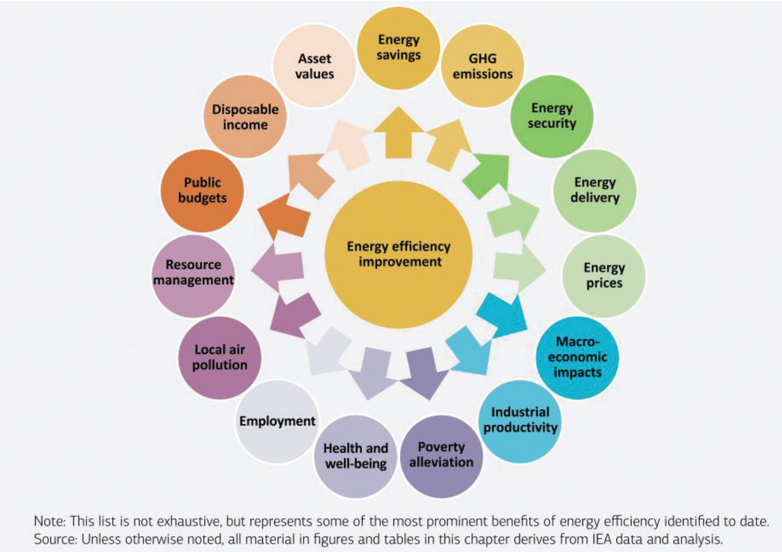
Energy efficiency is often viewed as the "invisible fuel", and is being touted by many as the "first fuel" due to its ability to reduce energy consumption and emissions, at a low cost. Indeed, the International Energy Agency (IEA) estimates that the total avoided energy consumption from energy efficiency improvements in 2014 stood at 520 million tons of oil equivalent, equivalent to 870 million tons of CO_2 of emissions avoided, and translated to global energy savings of USD 550 billion.[1] Due to its ability to render energy and emissions reductions while generating monetary returns in the form of avoided energy costs, energy efficiency improvements have emerged as a strong policy pillar for climate change mitigation in various nations.

Mitigation efforts with a focus on improving energy efficiency hinge on the assumption that the use of more energy efficiency technologies or appliances will lead to a decrease in overall energy consumption. However, economic theory suggests that such an assumption may not hold true due to the "rebound effect". The rebound effect refers to additional energy consumption resulting from energy efficiency improvements. The intuition behind the "rebound effect" is that due to energy efficiency improvements, the effective cost of energy consumption decreases, thereby inducing increased consumption of energy.

In this issue ...

Due to its negative impact on energy consumption and mitigation efforts, the "rebound effect" has commonly been mistaken as a vice. However, such sentiments may be one-sided. A 2014 report released by the International Energy Agency (IEA), "Capturing the Multiple Benefits of Energy Efficiency",[2] discussed the various benefits of energy efficiency, particularly in terms of social welfare by improving energy access, contributing to poverty alleviation, and energy security among others (see Figure 1). As such, when the increase in energy consumption is due to an increase in social welfare, the impact of the rebound effect should be regarded as neutral.

Figure 1 The Multiple Benefits of Energy Efficiency



Source: IEA (2014)[2]

While the rebound effect, by definition, is neutral, its negative impact on energy efficiency policies must be acknowledged. However, as long as the rebound effect remains below 100 per cent, policies targeting energy efficiency will remain effective and should be encouraged. The challenge comes when the rebound effect exceeds the initial energy efficiency improvement, a phenomenon termed "backfire". As such, an estimation of the rebound effect is critical for accurate policy evaluation of national energy efficiency issues.

Acknowledging the importance of the rebound effect, the Energy Studies Institute (ESI) organised a *Rebound Effect Conference* on 22 February 2016. The aims of this event were to acquaint participants with a broad overview of the rebound effect concept and to familiarise them with some of the cutting edge international studies on quantifying the rebound effect. It attracted a broad spectrum of participants from the public and private sectors, as well as academia.

In this issue of the Bulletin, we share some interesting insights gained from the Conference while also attempting to relate the international debate on the rebound effect to the Singapore context. The first article is by Professor Anthony Owen, Principle Fellow and Head of the Energy Economics Division at ESI. His article, "The Rebound Effect in Context", summarises the opening presentation he made at the Conference. He provides a comprehensive overview of the economic concepts underlying the rebound effect while drawing attention to the various behavioural complexities surrounding the concept. He contends that as the objective of energy efficiency policies is to maximize social welfare, a change in energy consumption is merely a reflection of adjustments in social welfare following a policy change. He concludes that although quantifying the size of the rebound effect is important in carrying out an accurate assessment of the impact of an energy efficiency policy on energy use, the design of policies meant to encourage energy efficiency need not explicitly target the rebound effect.

The second article is by Dr. Harry Saunders who was the second speaker at the conference. A Senior Fellow at The Breakthrough Institute and Founder, Managing Director of Decisions Processes Incorporated, he is widely known as an international expert on energy efficiency and often regarded as the "Godfather of Rebound". In his "General Overview of Rebound", Dr. Saunders provides a framework for understanding the concept of the rebound effect. He first distinguishes between households and producers which have different behaviours and underlying microeconomic concepts, then illustrates the direct, income and broader indirect effects of the rebound effect in both the household and producer context. He rounds up the article by drawing references to existing studies which quantify the rebound effect, emphasising that while instances of backfire are uncommon, the measurement of the rebound effect is crucial for climate change mitigation policy.

Dr. Mona Chitnis, Lecturer in Energy Economics, School of Economics at the University of Surrey, was the third speaker. She and Professor Steve Sorrell, from the University of Sussex, as well as Professors Angela Druckman and Tim Jackson from the University of Surrey and Professor Steven Firth of the University of Loughborough, quantified residential rebound effects in the UK. They estimated the rebound effect at 5 to 15 per cent in their study covering seven energy efficiency upgrades in UK households. It was reduced when accounting for capital cost adjustments. When they expanded their study to eight types of energy efficiency measures and three types of behavioural change, they found that the rebound effect was the most prominent for food waste eliminations (66 to 106 per cent), moderate for policies targeted at vehicle fuel use (25 to 65 per cent) and lowest for measures aimed at domestic energy use (0 to 32 per cent). Dr. Chitnis and the team also found that direct rebound effects were smaller than indirect effects in their first two studies. However, the results of their third study contradicted this finding. Their third study found that the direct rebound effect was stronger due to substitution effects. However, Dr. Chitnis acknowledges that the third study may have overestimated the extent of the rebound effect.

The last article, "The Relevance of the Rebound Effect in Singapore's Residential Energy Demand Policies" is by Mr Allan Loi, Energy Analyst at ESI, along with Ms Jazreel Yeo and Ms Carissa Tan, both former interns at ESI. For their article, they used international experience to create an econometric model to estimate the direct rebound effect in Singapore. Using price elasticity as an upper bound for direct rebound effect, their study estimated that the rebound effect would not exceed 2 per cent in the short run and 29 per cent in the long run. In alignment with international studies, they believe that the indirect rebound effect is likely to be larger than the direct effect.

We hope you find these articles of interest and welcome your views and comments.

Ms. Jacqueline Tao, Research Assistant
(On behalf of the ESI Bulletin Team)

1 IEA, *Medium-Term Renewable Energy Market Report 2015* (Paris: OECD/IEA, 2015) at https://www.iea.org/Textbase/npsum/MTrenew2015sum.pdf

2 IEA, *Capturing the Multiple Benefits of Energy Efficiency: A Guide to Quantifying the Value Added* (Paris: OECD/IEA, 2014) at http://www.iea.org/publications/freepublications/publication/Captur_the_MultiplBenef_ofEnergyEficiency.pdf

The Rebound Effect in Context

Professor Anthony D. Owen, Principle Fellow and Head of the Energy Economics Division at ESI

Remote Controls for VCR, TV, DVD, Surround Sound and Air Conditioner, 2007 (Permission under CC BY-NC- ND 2.0)

Introduction

The sole objective of energy efficiency policies should be to maximise social welfare, not to minimise energy demand. A major constraint to achieving this objective, however, is a measurement issue, since a single measure of social welfare requires a common numeriare; essentially a currency such as the dollar. The problem is that many goods are not traded through traditional markets or, if they are, the markets may be in some way "distorted". Thus dollar values are difficult to assign to many goods in the presence of such limitations.

To achieve a state of social welfare maximisation, a major requirement is that the price of energy (and all other goods for that matter) should reflect its scarcity (i.e. its value to society). So why not let Adam Smith's "invisible hand" determine how much energy society consumes?[1] In other words, let the market determine the optimal allocation of society's scarce resources. However, as Joseph Stiglitz (Nobel Prize winner in Economics, 2001) is reported to have observed: "the reason that the invisible hand often seems invisible is that it is often not there".

Free Market Imperfections

"Free" markets (i.e., free of external, usually government, interference) suffer from a number of potential inadequacies:

- They generate too little basic research;
- They generate too much pollution (un-priced environmental externalities);
- They deliver underinvestment in "social" goods (e.g. public health, defence, policing, education, etc.);
- They do not encourage perfect information;
- They deliver a lack of regulation (which can range across all sectors of an economy);
- They have weak enforcement of contracts and property rights; and
- They provide incentives to gain and maintain monopoly rents through the imposition of market barriers.

Where these imperfections exist, the conventional wisdom is that government should fill the voids. In the context of energy efficiency, it is the un-priced environmental externalities of energy use that tend to be of primary importance today.

Externalities

Externalities can be broadly defined as:
"Benefits or costs generated as an unintended by-product of an economic activity that do not accrue to the parties involved in the activity, and where no compensation is paid".[2]

In the context of environmental externalities of energy use, there are two major concerns: health and other damages from emission of local pollutants; and damages resulting from emission of greenhouse gases.

The 20th century witnessed historically unprecedented rates of growth in energy systems, supported by the widespread availability of fossil fuel resources. During the second half of the century, however, concerns associated with high levels of fossil fuel dependence began to surface. Two issues were of particular significance: the impact of modern energy systems on the environment and security issues associated with fuel supply lines.

Environmental concerns from fossil fuel combustion are not new, and have been evident in more localised areas for many hundreds of years. Today, local pollution from energy systems remains a threat to the health of the living environment. However, in the latter decades of the 20th century, pollution resulting from combustion of fossil fuels became a global concern, with the publication of credible scientific evidence that the planet's climate was changing as the result of a build-up of so-called greenhouse gases in the atmosphere.

Historically, regulatory instruments have been the basic mechanism for enacting environmental policy throughout the industrialised world. Environmental quality has been seen as a public good that the state must secure by preventing private agents from damaging it. Direct regulation involves the imposition of standards (or even bans) regarding emissions and discharges, product or process characteristics, etc., through licensing and monitoring. Legislation usually forms the basis for this form of control, and compliance is generally mandatory with sanctions for noncompliance.

The proposal to impose taxes on pollution, whilst more recent, is also far from new, having been advanced at the turn of the last century by the famous British economist Arthur Cecil Pigou as a means of reducing London's famous fogs (or smogs).[3] Pigou observed that pollution imposed uncovered costs on third parties that were not included in ordinary market transactions. His proposal was to tax pollution by means of a so-called externality tax in order to internalise within ordinary market transactions the damages caused by pollution. At the time Pigou's proposal was regarded as an academic curiosity, but several generations later it was rejuvenated as the core of the "polluter pays principle".

The fact that the polluter does not often pay, inevitably leads to a focus on government to remedy this market distortion through a range of possible policies designed to reduce energy demand and hence, hopefully, environmental degradation.

The Rebound Effect Concept and its Origin

Simply stated, the rebound effect: "conjectures an

Toaster Oven, 2005 (Permission under CC BY-NC- ND 2.0)

improvement in energy efficiency and compares the achieved reduction in energy use to the forecasted reduction in energy use that ignores consumer and market responses. Such consumer and market-wide responses are likely to occur because the energy efficiency improvement changes relative prices (and real income). The rebound effect is expressed as a percentage of the forecasted reduction in energy use that is 'lost' due to the sum of consumer and market responses".[4]

The origin of the concept is generally attributed to Stanley Jevons, a British economist who was writing at the height of the industrial revolution in Britain.[5] Jevons' concerns were largely similar to those of the current-day peak oil proponents, but in his case the fuel was coal. His proposition was that exogenous improvements in energy efficiency (i.e. not policy induced) for steam power generation and for steel production would effectively reduce the input price of coal, thus encouraging its greater use and, additionally, would raise its use through higher levels of economic growth. Ultimately this would lead to exhaustion of the UK's coal resources. It became known as the Jevons Paradox.

Current day peak oil proponents fail(ed) to understand that, frequently, the invisible hand does work reasonably well. High prices encourage technological change and hence greater supply of a resource and/or its substitutes. Jevons was not that naïve, but he died before his very substantial work on the estimation of the earth's resources was completed. However, with the benefit of hindsight, perhaps we can (unfairly?) observe that he failed to forecast the rise of oil and gas, and alternative transport modes, as substitutes for coal. He also failed to recognise the problem of climate change, although he would have been only too well aware of local pollution issues arising from coal combustion in London.

Separating Out the Components of the Rebound Effect

Improvements in the efficient use of energy may arise from two sources: either an exogenous (i.e. zero cost) increase in energy efficiency, or a policy-induced improvement in energy efficiency. Evolving technologies that produce goods which use less energy to deliver the same, or a higher, level of services than their predecessors, often drive the former. Many consumer-based electrical goods, such as television sets, notebook computers, mobile telephones, etc., would fall into this category. The latter are largely driven by government policies that attempt to overcome market barriers or distortions, and often involve a cost to the consumer. Examples would be the setting of minimum levels of energy efficiency for consumer white goods, a ban on the sale of incandescent light bulbs, emission standards for motor vehicles, etc.

The impact of the rebound effect arising from energy efficient improvements can be measured in terms of three broad effects:

- The price effect: since the energy efficient product is now relatively cheaper to operate, substitution will take place from more expensive products (direct impact);
- The income effect: resulting in a further increase in demand for the product in question plus other goods (indirect impact); and
- The macroeconomic effect: where the energy efficient product has significant ramifications throughout the economy. Such an impact would generally require a macro-economic model to estimate the extent of the rebound, and in practical terms there would be a requirement to ring-fence the sectoral range of the model to ensure that the exercise is containable.

If policy induced, then there may be costs involved and/or the good may take a different form:

- The energy efficient good may be more expensive than its predecessor; and/or
- The energy efficient good may provide greater attributes or "services" than its predecessor

  How does one disentangle the two?

There is also the issue of a time dimension. Consumers may be unwilling to purchase an energy efficient good if their existing product is still working satisfactorily, particularly if it involves a significant financial outlay. They may prefer to wait for the next generation of energy efficiency improvements for the product in question.

Conclusions

Energy efficiency policies should be based upon maximising social welfare, not minimising energy use. The rebound effect assists with this objective by providing feedback on the extent to which government policies can influence energy consumption. There is no requirement to design policies to mitigate the rebound effect since it is simply a measure of the gains and losses in social welfare arising from a specific policy.

It should be apparent, however, that estimation of the rebound effect is not a trivial matter, particularly when policy-based rebounds need to be calculated in order to judge their overall impact on energy use.

1 Adam Smith, *An Inquiry into the Nature and the Causes of the Wealth of Nations* (London: W. Strahan, 1776).

2 Anthony D. Owen, "Environmental Externalities, Market Distortions and the Economics of Renewable Energy Technologies", *The Energy Journal* 25, (2004): 129.

3 Arthur C. Pigou, *The Economics of Welfare* (London: Macmillan, 1920).

4 K. Gillingham, D. Rapson and G. Wagner, "The Rebound Effect and Energy Efficiency Policy", *Review of Environmental Economics & Policy*, 10, 1 (2016): 68-88.

5 William S. Jevons, *The Coal Question: An Inquiry Concerning the Progress of the Nation, and the Probable Exhaustion of Our Coal Mines* (London: Macmillan, 1865).

General Overview of Rebound

Dr. Harry D. Saunders, Senior Fellow at The Breakthrough Institute and Founder, Managing Director of Decisions Processes Incorporated

The economic phenomenon that has come to be known as "energy efficiency rebound," or simply "rebound," is straightforward to conceptualise, but exceptionally difficult to quantify in all its manifestations.

General Concept

The conceptual picture is this: an energy efficiency gain looks to the energy user very much like a reduction in energy price. As is well known in economics, a reduction in the price of a commodity induces an increase in its use in an amount governed by the price elasticity. Of course, the energy efficiency gain itself acts to reduce energy use so there is a tussle between the two forces to determine the net effect on energy use. The difference between the resultant energy use and what the energy use would have been without this elasticity effect is the rebound magnitude.

For example, if there is a new technology that promises to reduce energy use by 50 per cent while delivering the same quantity (and quality) of energy services, a naïve mental model would predict that the resulting energy use after introducing the energy efficiency technology will be 50 per cent of what it had been without the efficiency technology. But the user of such energy services will see this as a 50 per cent decrease in the effective price of the physical energy used to provide the energy service and will respond, typically, by using more of the energy service and thus more of the physical energy needed to supply it. If in the end the user consumes, say, 70 per cent of the energy used prior to introducing the technology, the price elasticity component will be 70 per cent – 50 per cent = 20 per cent.

To put this number into a more intuitive form, analysts typically define the rebound effect as

$$R = 100 - \frac{Actual\ energy\ savings}{Predicted\ energy\ savings}$$

where the "predicted energy savings" is the savings that would have been obtained were the technology gains to have been fully realised in an "engineering" sense (the 50 per cent number). The actual energy savings in this example is 100 per cent – 70 per cent = 30 per cent, so rebound is 100 per cent – 30 per cent /50 per cent = 40 per cent. The intuitive nature of this formulation can be appreciated by considering the case where actual energy savings equals predicted energy savings. Then, rebound would be calculated as 0 per cent from the rebound equation. In contrast, if actual energy savings were zero, we would say that rebound was 100 per cent (rebound ate up all the engineering savings). Greater than 100 per cent and we would have "backfire" (the efficiency gain leads to an absolute increase in energy use).

Taxonomy of Rebound in the Large: Households versus Producers

Rebound effects can occur anywhere in the economy, because energy efficiency gains can occur anywhere in the economy. Historically, most attention has been given to rebound effects that occur on the household side of the economy rather than the productive side of the economy. This is likely because energy efficiency gains on the household side (energy use within homes – for heating, cooling, appliances, consumer electronics – and for personal transportation – automobiles, light-duty trucks, recreational vehicles) are more in the realm of day-to-day experience for most individuals, even economists, than efficiency gains that occur on the productive side (industry, commerce, commercial transportation). However, to put things in context, only about one third of global energy consumption is consumed by households while some two-thirds is consumed by producers in creating and supplying goods and services to households.

So this is the primary partitioning of rebound effects – households vs. producers – and the distinction is given added importance by the fact that different behaviours apply in each sector, requiring different microeconomic paradigms. Technically, households act to maximise household utility while producers act to maximise profits. The resulting rebound effects need to be understood in the corresponding contexts.

Household-side Rebound

There are three mechanisms on the household side whereby rebound effects can become manifest. The first is the so-called "direct" rebound effect associated with the price elasticity response. An example would be the introduction of insulation to a dwelling in a winter clime resulting in the need for less heating fuel to provide the same amount of heat to the dwelling. The reduction in the quantity of fuel needed effectively reduces the price of fuel needed to provide the same heating service. A householder response might then be to either increase the temperature to a more comfortable level or heat more rooms during the winter months.

A second response is related to this. A reduction in the heating bill effectively increases household income, potentially causing a "direct" rebound effect associated with income elasticity. The household may use this added income to augment the price elasticity effect described above and increase heating fuel use still further.

A third response is similar to the second one, but is an "indirect" effect. Staying with the insulation example, a household may take the funds saved from the reduction in the heating fuel bill and use them to purchase goods or services that have taken energy to produce. This is sometimes referred to as embedded energy. A common example is a household that uses the heating fuel savings to fund foreign air travel.

Production-side Rebound

As with the household side, there are three distinct rebound mechanisms that can be distinguished on the production side. They are different, but follow a similar pattern.

The first is a "direct" effect that likewise is a response to an effective reduction in energy price. In this case, however, producers respond according to a different kind of elasticity, namely substitution elasticity. That is, producers adjust their production processes to substitute energy for other inputs to production – capital, labour and materials.

Rice Cooker, 2005 (Permission under CC BY-NC-ND 2.0)

Dehumidifier, 2009 (Permission under CC BY 2.0)

An energy efficiency gain in production does not deliver energy use reductions one-for-one with the engineering efficiency improvement, because such improvement effectively reduces the energy price making energy more attractive as a production input.

The second is comparable to the "income" effect on the household side and is likewise a "direct" effect. An improvement in the efficiency of using energy for production expands the space of profitable production possibilities. This is called the "output" effect. Increased output "drags up" the physical energy consumption used to produce the expanded output.

The third is an "indirect" effect. Energy efficiency gains reduce the price (cost) of producers' output, causing other producers who use that output (and ultimately end-use consumers) to increase their demand for that output, dragging up the physical energy consumption associated with expanded output. This effect involves a complex web of interactions among producers of intermediate and final goods and services, and end-use consumers.

Measuring Rebound

Since the rebirth of scholarly investigation into the rebound phenomenon by Brookes (1979) and Khazzoom (1980) – the topic having laid idle since the work of Jevons in 1865 – numerous scholars have undertaken studies to measure its magnitude in these various realms and the literature has exploded. Much work has been done on the household side of the equation, though much less has been done on the productive side. Results vary across sectors and regions, but the overwhelming bulk of the evidence is that rebound effects are substantial and need to be taken account of in projecting the effects of energy efficiency initiatives and policies. Most studies do not find much evidence of backfire generally, but there are instances of this. There is a growing consensus that rebound effects are likely much higher in developing economies than in the industrialised world.

The significance of the rebound effect for climate change mitigation policy is substantial. To the extent that forecasts of energy use fail to take account of rebound effects, it means there is less time than is commonly believed to develop and implement climate change mitigation policies. Countries that have made commitments to emissions goals at the Paris Summit need to ensure that they have not overestimated the role of energy efficiency policies in achieving these goals.

Rebound Effects from Improved Energy Efficiency in UK Households

Dr. Mona Chitnis of the Surrey Energy Economics Centre at the University of Surrey; Professor Steve Sorrell of the Science Policy Research Unit at the University of Sussex; Professor Angela Druckman and Professor Tim Jackson of the Centre for Environmental Strategy at the University of Surrey; and Professor Steven Firth of the University of Loughborough

Overview

The goal of our research was to estimate the magnitude of various 'rebound effects' following different types of energy efficiency improvement and behavioural change by UK households. The term 'rebound effects' refers to a range of economic responses to such measures, whose net result is to offset some or all of the anticipated energy and emission savings. For climate policy to be effective, such effects need to be anticipated, accounted for and, where possible, mitigated.

Our study included both the *direct* rebound effects associated with increased consumption of the relevant energy services (e.g. driving further in a fuel-efficient car); and the *indirect* rebound effects associated with increased consumption of other goods and services (e.g. spending the cost savings from a fuel-efficient car on an overseas holiday). In addition, we also allowed for the emissions 'embodied' in the energy efficient measures themselves (e.g. insulation materials). Our study provided the first estimate of the combined magnitude of these effects for UK households, and also illustrated how these vary with the type and cost of the measure and between different socioeconomic groups.

Electric Kettle, 2007 (Permission under CC BY 2.0)

Methods

To estimate rebound effects for households, we combined four types of estimates derived from four different analytical approaches.

First, estimates were required of the energy, emission and cost savings from the relevant measure, in the absence of any rebound effects. These can be produced from engineering models of household energy use, combined with data on the cost and energy/emission intensity of different energy carriers. For most measures, we utilised estimates from a bottom-up, engineering model of the English housing stock. This model allows estimates of the energy and emission savings from measures such as loft insulation, taking into account factors such as dwelling characteristics, thermal performance and the existing level of thermal insulation. For other measures, we relied upon simpler calculations.

Second, estimates were required of how the cost savings from the measure are re-spent on different goods and services or used to increase household savings. For this the estimates of the *expenditure elasticity*, *own-price* and *cross-price elasticities* of different categories of goods and services were required. These can be derived from econometric analysis. For our first paper, we used elasticities derived from a structural time series model. For the second paper, we estimated Engel curves using cross-sectional data. For the third paper, we estimated a system of consumer demand equations (AIDS) using time series data.

Third, estimates were required of the energy consumption, carbon emissions or GHG emissions that are ‘embodied’ in different household goods and services. These arise during the full life-cycle of the relevant goods and services, and include the emissions from production, distribution, consumption and disposal. To be accurate, such estimates should reflect the varying origins of those goods and services (e.g. UK, China, US), together with the corresponding differences in the energy/carbon/GHG intensity of production and distribution. We used estimates of the embodied GHG emissions of household goods and services from a quasi-multi regional environmentally extended input output model. We also modelled the GHG emissions associated with household savings and with government expenditure of product taxation revenues. Since the model is based upon GHG emissions from all stages of the supply chain, our rebound estimates are in terms of global GHG emissions.

Finally, estimates were required of the energy consumption, carbon emissions or GHG emissions that are ‘embodied’ **in the energy efficiency measures themselves** (e.g. LED light bulbs), together with those embodied in the relevant alternative (e.g. conventional incandescent bulbs). These may be obtained from life-cycle analyses of the relevant technologies. We derived these estimates from a number of life-cycle analyses identified in the secondary literature.

Study 1) Turning Lights into Flights: Estimating Direct and Indirect Rebound Effects for UK Households

This study estimated the income component of the rebound effects from seven measures that improve the energy efficiency of UK dwellings. The estimated rebound effects were averaged over a period of ten years.

We estimated the combined rebound effects from these measures to be in the range of 5-15 per cent, depending upon the time period examined and assumptions used. Allowing for the capital cost of the measure reduces the size of the estimated effects. The primary source of these rebound effects is the re-spending of the cost savings on non-energy goods and services, together with household savings, and the primary reason the estimated effects are modest is that these goods and services are much less GHG intensive than energy consumption itself.

Our results also allow for the embodied emissions of the energy efficiency measures themselves. In most cases, the embodied emissions of the relevant measures were less than 15 per cent of the direct and indirect rebound effect. However, there were exceptions (notably solar thermal) and the contribution of the embodied effect depends upon the time period considered.

Direct rebound effects were found to be much smaller than indirect effects, owing largely to the small share of energy in total household expenditure. However, the methodology only captures the income effects from energy efficiency improvements and not the substitution effects. These could either add to or offset the income effects for both energy commodities and other goods and services and therefore lead to either a higher or lower rebound effect.

Microwave Oven, 2010 (Permission under CC BY-NC-ND 2.0)

Study 2) Who Rebounds Most? Estimating Direct and Indirect Rebound Effects for UK Socioeconomic Groups

This study estimated the combined direct, indirect and embodied rebound effects for eight types of energy efficiency measures and three types of behavioural change by UK households, i.e., reducing internal temperatures by 1°C, eliminating food waste, and substituting walking or cycling for car journeys of less than two miles. It investigated how these effects varied with total expenditure, and derived estimates of rebound effects for income quintiles.

The main conclusions of this study were as follows. First, rebound effects appeared to be fairly modest (0-32 per cent) for measures affecting domestic energy use, larger (25-65 per cent) for measures affecting vehicle fuel use and very large (66-106 per cent) for measures that reduce food waste. Second, indirect rebound effects contributed most to these results, with the overall effect being dominated by the embodied emissions of non-energy goods and services. Third, rebound effects were generally larger for low-income households - mainly because they spend a greater proportion of their cost savings on GHG-intensive necessities such as food and drink. Fourth, direct emissions formed a much larger proportion of the total rebound effect for low-income households. Finally, measures that achieved cost savings in more than one category, as well as measures that were subsidised in some way, may be associated with larger rebound effects - although the commission impacts of providing the subsidies must also be taken into account. Allowing for capital costs modified these results, but not significantly. As with the previous study, this approach neglected substitution effects.

Study 3) Living Up to Expectations: Estimating Income and Substitution Effects from Efficiency Improvements by UK Households

This study estimated the rebound effects from efficiency measures affecting electricity consumption, heating fuels and road fuels for an average UK household. It departed from the previous studies by quantifying both the income and substitution effects from such improvements.

The results differed from those obtained in our other studies, confirming our expectation that the previous studies underestimated the rebound effects. We estimated a total rebound effect of 41 per cent, 48 per cent and 78 per cent for measures affecting domestic gas use, electricity and for vehicle fuels, respectively. In contrast to our other studies, the primary source of this rebound was increased consumption of cheaper energy services (i.e. direct rebound), and this was primarily driven by substitution effects.

However, this study may have overestimated the total rebound effect. The primary reason for this was our assumption that the own-price elasticity of demand for an energy commodity provides a suitable measure of the direct rebound effect for the energy services provided by that commodity. This holds only if energy prices are exogenous, energy service demand depends only on energy service prices and energy efficiency is constant. Absent these conditions, the own-price elasticity of energy demand will overestimate the direct rebound effect. Hence, the simplicity of using energy commodities rather than energy services in the demand model comes at a cost. It ignores the capital cost and embodied energy of the efficiency measure.

Policy Implications

Our results demonstrate the importance of accounting for rebound effects within policy appraisals. Failure to take account of these effects will lead to an overestimate of global emission savings.

The most effective way to mitigate rebound effects is likely to be through some form of carbon pricing. Ideally, a carbon pricing scheme should incentivise efficiency improvements and behavioural change, while at the same time mitigate any associated rebound effects and protect low-income groups.

Carbon pricing is not the only means to mitigate rebound effects. The wide variation in GHG emissions between households with comparable levels of expenditure indicates the potential for voluntarily shifting consumption patterns towards lower carbon options - such as reducing air travel or putting savings towards low carbon investments.

Finally, it is essential to recognise that cost-effective energy efficiency measures improve consumer welfare and (unless rebound exceeds 100 percent) reduce aggregate emissions. Hence, such measures should continue to be encouraged. What must change are the estimates of the global emission reductions that such measures will achieve.

Details of the Three Studies:

Chitnis, M. and Sorrell, S. (2015) "Living Up to Expectations: Estimating Direct and Indirect Rebound Effects for UK Household's", *Energy Economics,* vol. 52, Supplment 1, pp. S100-S116.

Chitnis, M., Sorrell, S., Druckman, A., Firth, S. and T. Jackson (2014) "Who Rebounds Most? Estimating Direct and Indirect Rebound Effects for Different UK Socioeconomic Groups", *Ecological Economics*, 106(C), pp. 12-32.

Chitnis, M., Sorrell, S., Druckman, A., Firth, S. and T. Jackson (2013) "Turning Lights into Flights: Estimating Direct and Indirect Rebound Effects for UK Households", *Energy Policy*, 55, pp. 234-50.

The Relevance of the Rebound Effect in Singapore's Residential Energy Demand Policies

Mr. Loi Tian Sheng, Allan, ESI Energy Analyst; Ms. Yeo Kai Jun, Jazreel, Former ESI Intern; and Ms. Tan Rou Xing, Carissa, Former ESI Intern

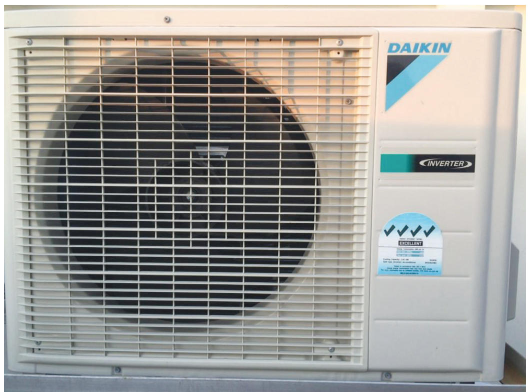
Air Conditioner, 2007 (Permission under CC BY 2.0)

Energy Efficiency and Electricity Market Liberalisation in Singapore

In recent years, energy efficiency has undoubtedly been rising steadily higher on Singapore's public agenda. Following the release of the *National Energy Policy Report* by the Ministry of Trade and Industry (MTI) in 2007, the efforts toward creating greener homes and lowering energy costs for residential consumers have clearly accelerated. The Report detailed a clear framework on how to tackle Singapore's energy needs and climate change concerns.

The initiatives listed in the Report included mandated energy efficiency policies, such as the Minimum Energy Performance Standards (MEPS) to ensure that the market offered more efficient appliances, and the Mandatory Energy Labelling Scheme (MELS) to help consumers make more informed purchase decisions, with respect to energy efficiency, when selecting an appliance for their household. The *Sustainable Singapore Blueprint 2015* revealed that 7 in 10 Singaporeans were choosing to purchase energy efficient or water-efficient appliances.[1] An earlier survey carried out in 2011/12 by the National Environment Agency (NEA) found that 57.3 per cent of respondents examined the energy labels before purchasing refrigerators and air-conditioners.[2] As average income levels rise, we can expect more consumers to choose energy-efficient appliances not only due to their increased affordability, but also due to greater public awareness of the availability of such appliances.

Full contestability in Singapore's electricity market is planned for 2018. This will give individual households freedom



Singapore Household Air Conditioner Inverter. Photo by Jazreel Yeo, May 2016.

to select an electricity retailer of their own choice. Such liberalisation is expected to reduce electricity prices as a result of increased price competition among the retailers.

The Rebound Effect

It is expected that utility costs will continue to fall as a result of the above-mentioned public efforts. However, it is simplistic to expect that in real life, consumers can realise the full extent of energy savings. One reason is the rebound effect, which refers to the phenomenon of people increasing their energy usage as a result of the cost savings brought about by a reduction in energy prices and gains from efficiency. The increased energy usage reduces the expected energy savings achieved by purchasing a new appliance,[3] or as a result of increased price competition among electricity providers.

Currently, policies designed to reduce household energy consumption are often cost-saving. The energy consumption estimates are typically based on engineering calculations.[4] These may differ significantly from actual energy-saving figures as a result of the rebound effect, which at the household level can have both direct and indirect implications on people's lives.[56] To analyse the potential extent of rebound in Singapore, we need to put it in the context of comparable studies conducted in other developed nations.

The direct rebound effect is generally defined as the increase in demand for energy consumption for a particular energy-efficient service in question (i.e., cooling from air-conditioners), after substituting an energy inefficient appliance that provides that service with a more efficient one. The new appliances purchased will lower the effective cost per unit of energy consumption, hence increase the purchasing power of the consumer which consequentially raises the tendency to use more energy. In Singapore, space cooling takes up the largest share of energy usage in households, with air-conditioners accounting for 36.7 per cent of households' energy consumption profiles.[7] Hence, it is expected that most of the direct rebound should come from space cooling.

There are relatively few quantitative estimates of direct space cooling rebound available. Two notable studies by Hausman[8] and Dubin et al[9] have come up with figures between one and 30 percent in the US.[10] Dubin et al went a step further with their statistical analysis of high efficiency air-conditioners operated by Florida Power & Light. The study found that very little rebound effect occurs in the summer months when outdoor temperatures are high, with estimates falling between 1-2 per cent energy savings. However, when demand for air-conditioners becomes more elastic during the colder months, rebound effects rise to as much as 13 per cent of anticipated energy savings.[11]

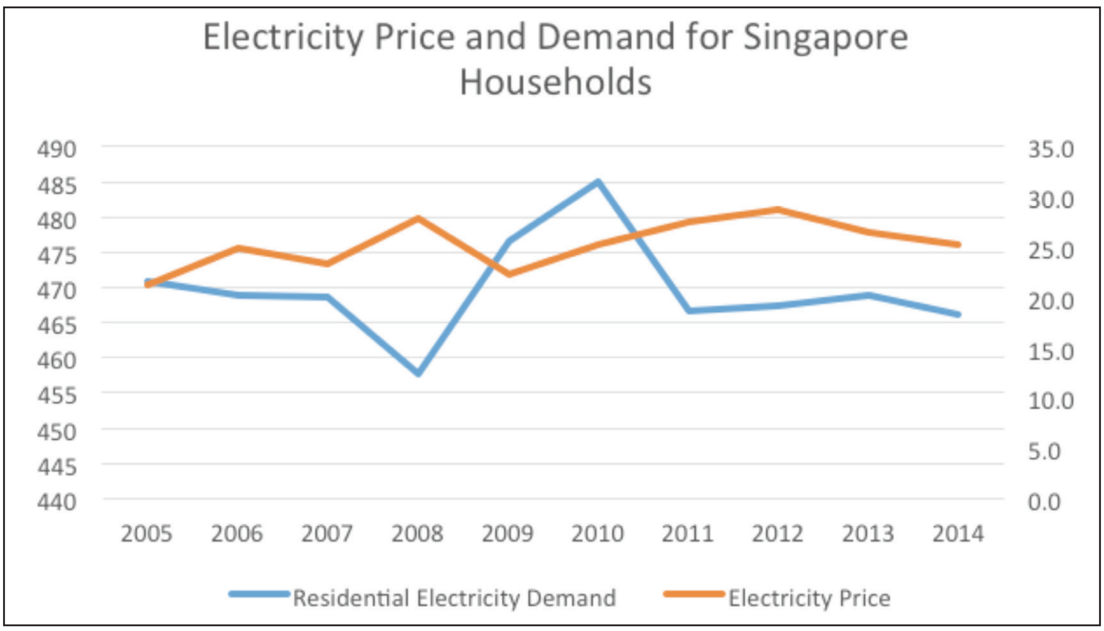
The Rebound Effect in Singapore

To extrapolate from the results in the summer months of Dublin's study, we can surmise that the direct rebound for each household in Singapore would also be very modest due to the tropical nature of the climate here. If the price elasticity of electricity demand can be taken as providing an upper bound value for direct rebound, an analysis of Singapore's per resident electricity consumption with macroeconomic variables suggests that it should not exceed 2 per cent in the short run, and 29 per cent in the long run.[12]

Indirect rebound effects, which lead consumers to purchase other goods and services that use or contain embodied energy, are even more challenging to estimate, owing in part to inadequate data, unreliable causal relationships, different definitions of the term and many other factors.[13] A couple of studies have highlighted the relative significance of indirect rebound effects and some, such as Brounen et al,[14] have gone as far as to state that the indirect energy consumption of households far exceeds direct consumption. While indirect energy consumption is more proportional to income and able to increase indefinitely, direct energy consumption shows signs of saturation, highlighting the increasing importance of indirect rebound over time. To put it in perspective, carbon emissions may fall as a result of reduced consumption of energy. However, any associated cost savings could lead to an increased probability of taking a flight on a holiday or driving a fossil-fuelled vehicle more frequently, thereby leading to higher indirect emissions. It is expected that indirect rebound effects should be higher than direct effects in Singapore, though not by much as consumer decisions being driven predominantly by salaries rather than energy savings.

Although the rebound effect leads to lower than expected reductions in energy use, cost savings and carbon emissions, care has to be taken in interpreting this as a purely negative phenomenon. There are multiple benefits that could arise, in the form of increased productivity and greater personal

Table 1: Electricity Price (¢/kWh) (Right Axis) and Demand (Left Axis) for Singapore Households.



Source: Energy Market Authority, 2015. Note: Electricity demand (kWh) is based on average monthly figures.

utilities derived from increased consumption of other goods and services. Consumption of these goods and services can even lead to improved health benefits and the alleviation of poverty,[15] both of which serve only to enhance welfare. Hence, explicitly setting policy targets to reduce the extent of rebound does not make sense. Furthermore, the household demand of energy is already price and income inelastic,[16] which suggests that energy use is a necessity, hence limiting the extent of rebound in Singapore.

Conclusion

Regardless of whether rebound brings about more benefits or costs to society, speculation is pointless. Before any conclusions can be drawn, policy-makers must find better ways to measure, quantify and perhaps even monetise such benefits so that they can be incorporated into existing policy frameworks.

Measurement of rebound is still in its infancy in Singapore and the degree to which rebound occurs here is largely unknown. Given the potential impact it has on policies, more research should be carried out on the rebound effect so as to provide a more complete and accurate evaluation of policy development. While rebound effects do not make energy efficiency measures entirely ineffective in reducing energy demand,[17] a sound understanding of rebound does force us to reassess the role of energy efficiency in tackling climate change and ensuring a sustainable Singapore moving forward into the future.

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17 J. Evans and L. C. Hunt, eds. *International Handbook on the Economics of Energy* (Cheltenham, UK and Northampton, MA): Edward Elgar Publishing, 2009).

Staff Publications

Internationally Refereed Journal Articles

Philip Andrews-Speed and Xunpeng Shi, "What Role Can the G20 Play in Global Energy Governance? Implications for China's Presidency", *Global Policy*, 7 (2016): 198-206.

Zeng Shihong, Hu Mimi and **Su Bin**, "Research on Investment Efficiency and Policy Recommendations for the Culture Industry of China Based on a Three-Stage DEA", *Sustainability* 8 (2016): 324-38.

Wang Qunwei, **Su Bin**, Zhou Peng and Chiu Ching-Ren, "Measuring Total-factor CO_2 Emission Performance and Technology Gaps Using a Non-radial Directional Distance Function: A Modified Approach", *Energy Economics* 56 (2016): 475-82.

Anton Finenko and Lynette Cheah, "Temporal CO_2 Emissions Associated with Electricity Generation: Case Study of Singapore", *Energy Policy* 93 (2016): 70-79.

Anton Finenko and Kamal Soundararajan, "Flexible Solar PV Deployments in Singapore: An Economic Assessment", *International Journal of Global Energy Issues* 3-4 (2016): 157-180.

Book Chapters

Lye Lin Heng and Melissa Low, "Energy and Smart Cities: Perspectives from a City-state, Singapore" in J. J. Manzano, N. Chalifour, and L. J. Kotzé (eds.), *Energy, Governance and Sustainability*, Edward Elgar Publishing (Cheltenham, UK; Northampton) (May 2016): 149-72.

Reports

Melissa Low, "Pathways from Paris: A Viewpoint from Singapore", in G. Canzi (ed.) *Paris Agreement: How it Happened and What Next*, Climate Strategies in Cooperation with Konrad-Adenauer-Stiftung (May 2016): 15-16. See http://www.kas.de/wf/en/33.45077/.

Shi Xunpeng, "The Impact of Low Oil Prices on Natural Gas and Implications for the Asia-Pacific", *Pacific Energy Summit 2016 Working Paper*, National Bureau of Asian Research, Washington, D.C.

Book Reviews

Christopher Len reviewed Mattijs Smits. *Southeast Asia Energy Transitions: Between Modernity and Sustainability* (Farnham, Surrey: Ashgate Publishing Ltd, 2015), in *Contemporary Southeast Asia, 38 (1),* (2016): 171-73.

Staff Presentations and Moderating

16 June Victor Nian presented, "INDC Implications for Southeast Asia", at Beijing University of Post and Telecommunications, China.

14 June Victor Nian presented, "Life Cycle Analysis of Energy Systems with Implications for Policy-Making", at Shandong University, China.

10 June Christopher Len presented, "China's Rise as a Maritime Power: The Energy Security Dimension", at the Institute for Security and Development Policy, Sweden.

3 June Victor Nian presented, "A Comparative Cost Assessment of Energy Production from a Central Heating Plant or Combined Heat and Power Plant", *CUE2016-Applied Energy Symposium and Forum 2016: Low Carbon Cities and Urban Energy Systems*, Jinan, Shandong, China.

3 June Su Bin presented, "Singapore's Decarbonisation Pathways (2010-2030-2050): Analysis from MARKAL Modelling" at *Energy Innovation 2016*, Suntec Singapore Convention and Exhibition Centre, Singapore.

1 June Gautam Jindal presented, "Updates from the Bonn Climate Change Conference" at the *Post-Paris Workshop: ASEAN Member States in Meeting Global Targets* organised by the Asia Europe Foundation, Jakarta, Indonesia.

31 May Victor Nian presented, "INDC Implications for Southeast Asia", at the Tokyo Institute of Technology, Japan.

30 May Gautam Jindal presented, "Paris Agreement: Reshaping International Climate Change Diplomacy" in the session on "How Countries Respond to Climate Change" at the *Teachers' Conference 2016*, Singapore.

26 May Su Bin presented, "Multi-region Comparisons of Energy and Emission Performance using Decomposition Analysis", at Hunan University, Changsha, China.

25-26 May Philip Andrews-Speed presented "Powering ASEAN: Can the Nordic Model Work?" at the HAPUA-AEMI Workshop, Jakarta.

25 May Melissa Low presented "Regional Climate and Energy Action Plan Update: International Professional Fellows Recommended Replicable Policies and Practices" at the Metropolitan Washington Council of Government, Washington, D.C.

18 May Victor Nian presented, "INDC Implications for Southeast Asia" at *EnerData Energy Seminar*, at the NUSS Suntec City Build House.

18 May Anthony D. Owen presented "The Economic Viability of Nuclear Power in Energy-only Liberalised Markets", at the Grote Lecture, organised by UCL Adelaide, Adelaide, South Australia.

11 May Shi Xunpeng presented "China's Natural Gas Policy Reform" at *Argus Australia and Global LNG Markets,* Brisbane.

10 May Jacqueline Tao and Anton Finenko presented "Solar PV Business Climate in Singapore" at the *Asian Power Utility Forum 2016*, Conrad Centennial, Singapore.

6 May Philip Andrews-Speed presented "Powering ASEAN: Can the Nordic Model Work?" at the Asia *Clean Energy Forum*, Manila.

6 May Shi Xunpeng presented "ASEAN'S Future Energy Mix: The Role of Coal" at *Global Energy Security and Climate Change Challenges: The Future of Coal and Chances for Clean Coal Conference*, Seoul.

6 May Shi Xunpeng moderated "Global Trends in Energy and the Role of Coal in the World's Energy Mix" at *Global Energy Security and Climate Change Challenges: The Future of Coal and Chances for Clean Coal Conference*, Seoul.

3 May Melissa Low presented "Introducing Climate Change and Sustainable Development Policies in Singapore" at the Metropolitan Washington Council of Government, Washington, D.C.

21 April Shi Xunpeng presented "Spillover Effects of Restricting Coal Consumption and its Impacts on Development", at the United Nations Conference on Trade and Development 8th Multi-year Expert Meeting on Commodities and Development, Geneva.

15 April Li Yingzhu presented, "Economic, Social and Environmental Impacts of Energy Subsidies: Case Study of Malaysia" at *ERIA Working Group Meeting*, Bangkok, Thailand.

14 April Melissa Low moderated ESI Seminar "Non-State and Sub-National Actors Climate Pledges and their Role at Paris COP21", delivered by Dr Angel Hsu, Assistant Professor of Environmental Studies at Yale-NUS College and Adjunct of the Yale School of Forestry and Environmental Studies, ESI.

12 April Su Bin presented, "Multi-region Comparisons of Emission Performance: The Structural Decomposition Analysis Approach" at Nanjing University of Aeronautics and Astronautics, Nanjing, China.

Staff Media Contributions

Victor Nian was interviewed by *The Business Times* on nuclear technology developments, 9 June 2016.

Philip Andrews-Speed was interviewed by *Asian Oil & Gas Monitor* on China's ports and "One Belt One Road", 24 May 2016.

Philip Andrews-Speed was interviewed by *Radio Free Asia* on China's declining oil investment, 24 May 2016.

Philip Andrews-Speed was interviewed by *Geo-politics* on China's air pollution, 5 May 2016.

Philip Andrews-Speed was interviewed by *China Radio International* on oil exporters failing to agree on a production freeze, 18 April 2016.

Philip Andrews-Speed was interviewed by *Radio Free Asia* on China's declining oil production, 13 April 2016.

Anton Finenko and Tao Yujia, "Making Business Case for Solar PV in Singapore Happen", *Asian Power*, 12 April 2016.

Philip Andrews-Speed was interviewed by *Carbon Reporter* on China's prospects for gas, 4 April 2016.

Shi Xunpeng was quoted in *People's Daily*, "Global Governance of Nuclear Security", 31 March 2016.

THE 40th IAEE INTERNATIONAL CONFERENCE

Meeting the Energy Demands of Emerging Economies: Implications for Energy and Environmental Markets, 18-21 JUNE 2017 SINGAPORE

Skyline of Marina Bay, Singapore. Photo courtesy of the Singapore Tourism Board.

Conference Overview

The Energy Studies Institute invites you to participate in the 40th IAEE International Conference, which will be held at the iconic Marina Bay Sands Hotel, Singapore, 18-21 June 2017, with the main theme *Meeting the Energy Demands of Emerging Economies: Implications for Energy and Environmental Markets*.

The ten countries that make up the Association of Southeast Asian Nations (ASEAN) are exerting an increasingly important influence on global energy trends. Underpinned by rapid economic and demographic growth, energy demand in the region has more than doubled in the last 25 years, a trend that is set to continue over the period to 2040. Given Southeast Asia's role as a global growth engine, understanding what is shaping energy markets in this vibrant region and the implications for energy security and the environment is vital for policy-makers and anyone with a stake in the energy sector. (IEA, *Southeast Asia Energy Outlook, 2015*).

However, as this will be a truly international conference, the focus will be on energy issues interpreted in their broadest global context. Of course, energy policies cannot be addressed in isolation from their local and global environmental impacts, and many conference sessions will address issues relating to this interdependence.

Topics To Be Addressed

The conference will address the full range of energy issues that may be expected to be commanding the attention of academics, analysts, policy-makers, and industry participants in 2017. Possible topics include, but are not limited to:

- Security of energy supply: at what price?
- A growing role for nuclear?
- Energy poverty and energy subsidies: how can the link be broken?
- The economics of gas spot trading
- Renewable and alternative sources of energy
- Energy policy options in a carbon constrained world
- Developments in LNG markets
- Energy modelling
- Emission trading schemes
- The econometrics of oil and gas markets
- Energy sector investment
- Liberalised power markets: way to go?
- Oil and gas: global resources, reserves, and production.

CONFERENCE VENUE

In addition to its convention facilities, the Marina Bay Sands complex also hosts a hotel, a casino, and a large shopping and dining complex, all in a sweeping garden setting overlooking Marina Bay. The hotel itself has the world's largest rooftop pool, which stretches 150 metres across the hotel and offers breath-taking city-skyline views. A room reservation block has been negotiated with the hotel at a very favourable rate, but this is expected to be filled very quickly. Rooms in nearby hotels around Marina Bay will also be offered, as will less expensive accommodation located elsewhere in the city. The Marina Bay Sands complex has its own MRT (train) station, Bayfront, making it easily accessible to those staying off-site. For further information about the venue please refer to: www.marinabaysands.com.

Concurrent Session Abstract Format

Those offering to make concurrent session presentations must submit an abstract that briefly describes the research or case study to be presented no later than 13 January 2017. The abstract must be no more than two pages in length, and must include an overview of the topic including its background and potential significance, methodology, results, conclusions, and references (if any). All abstracts must conform to the structure outlined in the template. Abstract must be submitted online. Please see www.iaee2017.sg for details.

Presenter Attendance at the Conference

At least one author of an accepted paper or poster must pay the registration fees and attend the conference to present the paper or poster. The corresponding author submitting the abstract must provide complete contact details. Authors will be notified of the status of their presentation or poster by 1 March 2017. Authors whose abstracts are accepted will have until 14 April 2017 to submit their final papers or posters for publication in the online conference proceedings. While multiple submissions by individuals or groups of authors are welcome, the abstract selection process will seek to ensure as broad participation as possible.

Therefore, each author may present only one paper or one poster in the conference. No author should submit more than one abstract as its single author. If multiple submissions are accepted, then a different author will be required to pay the registration fee and present each paper or poster. Otherwise, authors will be contacted and requested to withdraw one (or more) paper(s) or poster(s) for presentation.

Abstract submission deadline

Friday 13 January 2017

www.iaee2017.sg

STUDENT EVENTS

Students may, in addition to submitting an abstract, submit a paper for consideration in the IAEE Best Student Paper Award Competition.

Students are also encouraged to participate in the Student Poster Session and to submit a paper for consideration in the Special PhD session. The abstract format and submission process for the poster session is identical to that for concurrent session papers.

Students may inquire about scholarships covering the conference registration fee. For more information, please visit www.iaee2017.sg.

Recent Events

6 April, The Governance of Nuclear Energy: Perspectives for Non-Nuclear Countries (ESI Seminar)

Mr. Marc-Gérard Albert

Mr. Marc-Gérard Albert, Director for International Affairs, French Institute of Nuclear Safety and Radiation Protection (IRSN) delivered two presentations on the governance of nuclear energy. His first presentation examined nuclear governance in the context of national governments' sovereignty versus their international commitments to non-proliferation and also nuclear liability. He honed in on the soft power of international insights and the leverage that they put on national nuclear programmes. He noted the legitimate interest in or concern about the nuclear activities of other countries, and the necessity that governments be assured that they will not be exposed to any detrimental effects. Amidst these diverging interests, the governance of nuclear energy has assumed an increasingly international dimension and various cooperative schemes have been developed, which allow, to some extent, states to be informed of, to influence or to get involved in foreign nuclear programmes. His second presentation looked at ways to manage nuclear accidents and deal with radioactive contamination. Mr. Albert attributed the limited effectiveness of international mechanisms to manage the transnational consequences of nuclear events, to the difficulty firstly in assessing risks in a comprehensive and balanced perspective, and secondly in determining optimal measures to deal with radioactive contamination, especially those pertaining to the evacuation of people or the decontamination of affected areas.

14 April, Non-State and Sub-National Actors Climate Pledges and Their Role at Paris COP21 (ESI Seminar)

Dr. Angel Hsu

Dr Angel Hsu, Director of Yale Data-Driven Environmental Solutions Group, Assistant Professor of Environmental Studies at Yale-NUS College and Adjunct of the Yale School of Forestry and Environmental Studies delivered a presentation on non-state and sub-national actors' climate action. Dr Hsu addressed the significance of sub-national government and non-state actors by analysing and contextualizing their efforts alongside those of nation states based on research findings by Yale's Data-Driven Environmental Solutions Group (Data-Driven Yale). She also discussed the significant role of non-state and sub-national actors in the Paris COP21 talks in December 2015.

ESI's participation at the 39th IAEE International Conference

The 39th International Association for Energy Economics (IAEE) International Conference was held in Bergen at the Norwegian School of Economics from 19-22 June 2016. The theme of the conference was "Energy: Expectations and Uncertainty". Scholars from around the world attended this conference, presenting cutting edge research papers in areas such as energy efficiency challenges and policies, climate change and the energy sector, and energy and environmental innovation and technology development.

As the host of the next IAEE International Conference, ESI was proud to have Professor Chou Siaw Kiang, ESI's Executive Director, lead a team of seven to this prestigious conference. The team took this opportunity to raise the profile of ESI as one of Asia's leading energy policy think tanks, as well as to network with the distinguished energy economists.

Four of our staff presented ESI's work and gained valuable comments. Below are summaries of the four papers.

Value of Solar Photovoltaics in Singapore: Calculating the Merit Order Effect

Presented by: Professor Anthony D. Owen
On behalf of: Mr. Anton Finenko, Mr. Gautam Jindal and Dr. Liu Xiying, Sophie

Professor Anthony Owen

With no indigenous fossil fuel resources, and a poor wind resource, solar photovoltaics (PV) is the main focus for additions to Singapore's domestic energy supply. However, a high penetration of PV in the power sector would result in a number of costs and benefits that need to be quantified in order to ensure prudent government policies for "supporting" the widespread adoption of PV in Singapore. The concept of the "value" of solar stems from the limitations of using the levelised cost of electricity (LCOE) as a metric for evaluating the unit cost of alternative power generation technologies that include variable (i.e., intermittent) renewable energy (VRE) supplies. This paper thus addresses this issue by deriving an overall economic value that solar PV brings to society.

Professor Owen illustrated with a description of the National Electricity Market of Singapore (NEMS) before discussing the various benefits solar PV can bring. Specifically, generation capacity benefits, transmission and distribution costs and benefits, market price benefits, grid reliability costs and benefits and environmental costs and benefits were discussed. After outlining the basics of the methodology employed and the model components, Professor Owen illustrated that the injection of 600MW of PV into the NEMS will generate between SGD362 million to SGD380 million of annual monetary savings through reductions in average market clearing price as a result of the merit order effect. The annual monetary savings are expected to increase with larger shares of solar, reaching a potential SGD680 million to SGD723 million with a hypothetical 2 GW of solar energy. Avoided carbon under a 600MW scenario will be around 320 Kt CO_2, equivalent to about SGD12 million of avoided carbon costs. The figure is expected to rise to around 1 Mt CO_2, or SGD40 million, of avoided carbon and carbon costs respectively, with 2 GW of solar PV capacity. Correspondingly, the benefits of the merit order effect would have to be balanced with the increased cost of procuring additional reserves.

Transition to Hub Indexation and More Flexible Natural Gas Contracts in East Asia

Presented by: Dr. Xunpeng Shi
On behalf of: Mr. Hari M. P.

Dr. Xunpeng Shi

As interest grows in the transition away from oil indexation of LNG contracts to market-based pricing in East Asia, this paper utilises a World Gas Trading Model to address key questions such as the impact of a switch to an East Asian spot benchmark for gas and LNG trade on global gas markets on production, consumption, trade, price and the procurement cost of natural gas. It also examines the potential difference between utilising a Shanghai benchmark price and a Tokyo benchmark price, and the impact of removal of destination clauses.

The paper opens with an overview of the current global gas market circumstances and the increasing prominence of East Asian countries. A critique of the current oil indexation pricing mechanism in East Asia is presented, along with alternative pricing mechanisms available in global markets. After a brief description of the model and scenario setting, it is noted that both transition to hub indexation and flexible LNG trade contracts are of interest to East Asian importers and can also benefit exporters. However, a transition to hub indexation may take a long time because such indexation needs a hub that has a liberalised, or competitive market, and there is not yet such a place in the region. The study also illustrates that the location of a pricing benchmark hub does not actually matter. Given the diversity of the East Asian market, it is likely that there will be more than one hub and that they will offer different benchmark prices. The impact of relaxing the destination clause outweighs any change in the pricing formula, except in China, where the presence of pipeline imports makes the price formula change of equal importance to the destination flexibility.

The following policy suggestions can be extracted from the study: (1) East Asian importers should jointly work towards a hub indexation pricing formula for their gas contracts and removal of the destination clause; (2) The removal of the destination clause should be given higher priority than indexation change because it does not need domestic market liberalisation and thus is easier to implement compared to spot price indexation. However, in China, given the significant benefits of a change in the price benchmark, it should be given consideration equalling that for the destination clause removal; (3) Importers and exporters should cooperate to build trading hubs as both will benefit from reduction in procurement costs; (4) Given the impending oversupplied market in East Asia, it is an opportune time to facilitate the changes.

China's Carbon Emissions Embodied in Normal and Processing Exports and Their Driving Forces, 2006–2012

Presented by: Dr. Su Bin

Dr. Su Bin

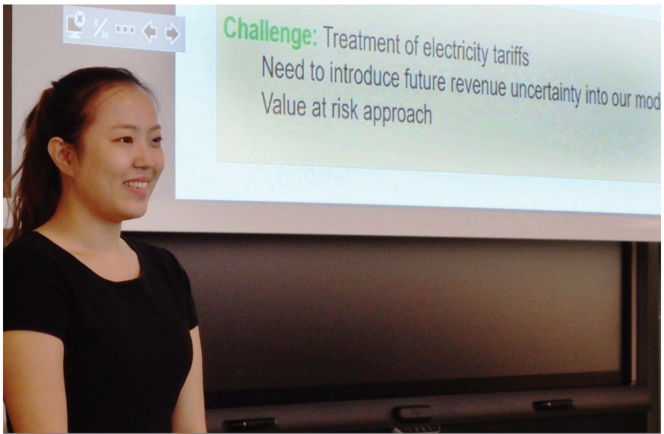
With globalization making the relationships among world countries closer than before through international trade, the phenomenon of "carbon leakage" through embodied emissions in trade will remain and even increase in absolute volume. One of the world's largest CO_2 exporters is China, which was exporting more than 20 per cent of its total annual CO_2 emissions to foreign countries after year 2000. Around half of China's exports are processing exports, which are exports of end products from assembling/ processing imported intermediate inputs exempted from Chinese tariffs which will eventually be sold overseas. It is estimated that the embodied emissions per dollar of processing exports are much lower than the emissions embodied per dollar of normal exports. Thus, differentiating the normal and processing exports in embodied emissions and understanding their contributions to China's total CO_2 emissions were the main objectives of this study.

The paper opens with a broad overview of the subject, and then explains the methodological framework (extended I-O framework with structural decomposition analysis applied to investigate the driving forces behind embodied emission changes) and data sources. It is best to use the extended model for analysing the trade-related embodiment, especially for processing exports because with the traditional I-O model, the emissions embodied in processing exports are over-estimated by more than 70 per cent while the rest of the embodiments are under-estimated. Among the four factors in SDA analysis for the 2006-2012 period, the emission intensity effect plays the major role in reducing the embodied emissions, implying the importance of emission efficiency in reducing the emissions and offsetting the increasing demand for Chinese exports from around the world.

One of the key takeaways from the study is that it is important to understand the impacts of embodied carbon emission in trade when formulating national reduction targets in the INDCs. For example, the emission efficiency improvements in China in the whole analysis period helped to reduce the embodied emissions in exports by about 2,500 Mt CO_2, and this should be accounted for. Emission efficiency improvements which reduce embodied emissions, are mainly the result of improving energy efficiency, optimising the energy mix through using more renewable energy, and employing technologies such as carbon capture and storage. As China's demand is driven mostly by investment and international exports, it is necessary to restructure the industrial sector in order to reduce the export of energy/ emission intensive products, while encouraging investment in green industries.

Moving beyond LCOE: Impact of Various Financing Methods on PV Profitability

Presented by: Ms. Jacqueline Tao
On behalf of: Mr. Anton Finenko



Ms. Jacqueline Tao

The financing gap is increasingly highlighted as a major barrier in the mass deployment of renewable energy projects, such as solar. One of the reasons behind the high financing costs seems to be the underlying capital structure of such projects. Thus, this study addresses how different financing methods may affect PV profitability.

The paper opens with a brief discussion of the discounted cash flow model and the various scenarios and tariff structures employed. It then explains the weakness of the levelised cost of electricity (LCOE) metric which is commonly used in literature to assess grid parity and profitability, then introduces the breakeven tariff as an alternative grid parity and profitability metric. As a static metric, it also has shortcomings. The Value at Risk approach, when accompanied by the LCOE, breakeven tariff and other profitability metrics, can provide a holistic view of PV profitability. In the paper, several different financial structures are simulated.

The study highlights the importance of debt financing (through bank loans or fixed income capital market instruments) to ensure PV profitability. This implies the need to familiarise lenders with the risk structure of PV projects to reduce barriers for bank lending. Other incentives, such as green investment credit schemes, could be extended to financial institutions to incentivise debt injection into PV projects. The use of bond financing increases project profitability due to the implicit benefits offered by tax breaks and the timing of cash flows. As such, there should be a push for such instruments. However, in the case of Singapore, the use of such instruments may be limited given the limited scale of PV projects, especially when compared to the minimal issuance size for bonds. Alternatives, such as project bundling and small cap bond issuances are thus explored. Another challenge faced by Singapore PV developers is that the maturity dates for bond instruments are unable to coincide with the payback period for the project, thus indicating potential financial distress at the bond repayment year. Therefore, with results indicating limited potential cost reductions through capital structure changes, alternatives such as innovative risk management tools, as well as opening other potential revenue streams, should be considered.

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New Staff

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Ira Martina DRUPADY joined the Energy Studies Institute in June 2016 as a Research Associate for the Policy and Law for Nuclear Safety and Security Project. Ira spent the previous three years consulting for Government of Australia aid programmes in Indonesia on climate change financing, forestry sector governance and green economy. Prior to that, she researched energy security governance issues for the Lee Kuan Yew School of Public Policy, where she also received her Masters in Public Policy in 2010. During this period, Ira co-authored the book, *Energy Access, Poverty, and Development: The Governance of Small-Scale Renewable Energy in Developing Asia* (Ashgate 2012). Ira previously worked for the Economist Intelligence Unit, Asia-Europe Foundation and *Business Week* magazine. She received her Bachelor of Arts degree from the National University of Singapore in 2002.

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