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Special Edition - Energy and Pollution

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Special Edition: Energy and Pollution

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This is the first in a series of 'Special Issues' which will gather together a number of current and policy related papers on a particular theme. This first collection of papers draws together research from across the UK on the themes and implications of energy and climate change. As the guest editors note, we hope this collection stimulates discussion amongst the business and policy making communities in Scotland.

Cliff Lockyer
Managing Editor,
Fraser of Allander Economic Commentary
January 2011

Footnotes in the articles are listed as endnotes at the end of each article.

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Foreword

Michael Timar,
Energy Specialist and Partner at PwC in Scotland

Climate change, emissions reduction, renewable energy, energy efficiency and fuel poverty: subjects that are both very topical and very emotive across the globe and at all levels in society.

At the tail end of 2010 we had the United Nations Climate Change Conference in Mexico, the UK government announcing its proposals for electricity market reform (many of which are focused on providing the incentives to invest in nuclear and renewable energy) and in Scotland, one of the coldest and snowiest starts to a winter ever, with the country almost brought to a standstill and rumours of potential shortages of heating oil.

Against this backdrop, the Scottish Government has set out a bold vision. The Climate Change (Scotland) Act sets world leading targets for emission reductions by 2020 - at levels greater than those set by the UK government or the EU. Targets have also been set for electricity generation- 80% of our energy consumption should come from renewable sources by 2020. Renewable energy has been identified as a platform for major economic growth, through capital investment, the export of power and the export of know how.

Is this vision achievable?

Scotland has significant natural resource in the form of wind and marine power, and a long history of engineering expertise. We have industry leaders in the development of renewable power generation in SSE and Scottish Power Renewables, and in wave power technology development with companies such as Pelamis Wave Power and Aquamarine Wave Power.

Scotland's oil & gas industry has many years of experience operating in the harsh North Sea environment that will be important to the development of offshore wind power. The Scottish Government has supported this vision in recent months with the launch of the £70m National Renewables Infrastructure Fund.

At this high level, the signs are certainly positive. Start to peel back the layers however, and the complexity of this subject, with its interplay of political, economic and moral factors becomes evident.

Much of the work that PwC is currently doing in the sector is on how to attract the investment that will ensure the build out of renewable generation and in particular offshore wind. But there are many other issues to be explored.

- How should emissions be measured - based on production within our geographic borders or on the generation required to support Scotland's consumption regardless of origin?
- How can a Scottish climate change policy succeed in an economy and electricity market which is embedded in the UK and EU markets?
- What independent levers does the Scottish Government have in achieving the targets they have set?
- What part might our communities play in emissions reduction and energy efficiency?
- Does the "rebound effect" mean that planned energy efficiency savings will only be partially realised due to our propensity to consume?
- To what extent is the consumer prepared to pay for a future where power generation is "greener", and what are their preferences in choosing between alternative impacts?
- What might Scotland's future generation capacity look like - embedded as it is within a UK market that will require a balance across coal, gas, nuclear, wind, marine and hydro to provide for a secure and sustainable supply of power?

Published by the Fraser of Allander Institute in partnership with PwC, the following papers discuss these questions and are each thought provoking in their own way.

They will help us understand just some of the complexities that will need to be addressed in achieving the targets and ambitions that have been set out for Scotland's future as a leader in the world of climate change.

Introduction

Karen Turner, Guest Editor
ESRC Climate Change Leadership Fellow
University of Stirling

Janine De Fence, Guest Editor
Fraser of Allander Institute
University of Strathclyde

Alongside its research into the Scottish economy, the Fraser of Allander Institute has a growing reputation for research into environmental and energy issues that impact the Scottish and UK economies. FAI researchers and associates currently hold a number of grants from the UK Research Councils and the EU FP7 programme to investigate issues such as the introduction of different renewable technologies, energy efficiency and pollution embodied in interregional and international trade flows. Moreover, the researchers on these projects are all active members of the Scottish Institute for Research in Economics (SIRE) Environmental and Energy Economics (EEE) Workshop, which has been set up to foster collaborative activity among colleagues at the eight main Scottish universities.

The publication of this special issue of the Fraser Economic Commentary coincides with the end of a project funded by the UK Economic and Social Research Council (ESRC), based at the Universities of Strathclyde and University of Stirling, and with the support and involvement of the FAI team throughout. The project is one of six ESRC Climate Change Leadership Fellowships awarded in 2008. Therefore, it is an exciting development that this special issue, under the guest editorship of the Fellowship team, gives us the opportunity to highlight some of the cutting edge economic research into energy and environmental problems being conducted primarily at the Universities of Strathclyde and Stirling, but involving collaboration with colleagues throughout the UK and across the world.

Our first two papers, co-authored with a number of Fellowship collaborators, focus on our research into accounting for carbon generation associated with economic activities in the UK national and regional economies. These papers present non-technical expositions of new results, not yet published in the academic literature. This is entirely consistent with the priority placed on knowledge exchange that is shared by both the ESRC Climate Change Leadership Fellowship programme and by the Fraser of Allander Institute.

In the other five papers, we present papers from other research projects based at the Universities of Strathclyde and Stirling, but which share the common theme of contributing to knowledge and understanding of the energy and environmental problems underlying climate change. The third paper, contributed by colleagues based at FAI provides an overview of Scottish Climate Change Policy, while the fourth, titled ‘Stimulating Diffusion of Low-Carbon Technology: Evidence from a Voluntary Program’, contributed by colleagues at Stirling, provides perspectives from policies implemented in the US.
In the final three papers, we turn our attention specifically to energy issues. The fifth paper, titled ‘The Rebound Effect: Some Questions Answered’ focuses on some key issues arising from another ESRC funded project, based at the Universities of Stirling and Strathclyde on the unanticipated impacts of increased energy efficiency. This is followed by two papers focussing on specific areas of energy policy concern: one titled ‘Preferences for Energy Futures in Scotland’, contributed by colleagues based at Stirling, and the other titled ‘The electricity generation mix in Scotland: The long and windy road?’, which closes the issue by reporting on research funded by the Engineering and Physical Sciences Research Council (EPSRC) at the University of Strathclyde.

We hope that this special issue of the Fraser Economic Commentary, the first of its kind, stimulates discussion on a variety of climate change related topics among the academic, business and policy communities within Scotland and beyond.

An input-output carbon accounting tool: with carbon footprint estimates for the UK and Scotland

Karen Turner (Stirling Management School, Division of Economics, University of Stirling)
Norihiko Yamano (OECD)
Angela Druckman (RESOLVE, University of Surrey)
Soo Jung Ha (Korean Research Institute for Human Settlements)
Janine De Fence (Fraser of Allander Institute, University of Strathclyde)
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Acknowledgements

The research reported in this paper has been carried out with the support of the ESRC Climate Change Leadership Fellow project "Investigating the pollution content of trade flows and the importance of environmental trade balances" (ESRC ref. RES-066-27-0029), based at the Universities of Stirling and Strathclyde. The authors also acknowledge the support and cooperation of the Organisation for Economic Cooperation and Development in hosting Dr Soo Jung Ha and working with her to construct the dataset used to analyse the pollution content of imports to Scotland and the UK. We are also grateful to colleagues at the Scottish Government and the Stockholm Environment Institute for advice and assistance in constructing the datasets used. Finally, we are grateful to Randall Jackson, Regional Research Institute, West Virginia University, and Kim Swales, Department of Economics, University of Strathclyde, for their comments and advice on the accounting methods employed here.

1. The research programme

In 2008, the UK Economic and Social Research Council (ESRC) awarded six Climate Change Leadership Fellowships (CCLFs) to address key research issues and innovative approaches in mitigating/or adapting to climate change. Of the six Fellowships, led by Dr Karen Turner (University of Stirling, formerly of the University of Strathclyde) we have engaged in a programme of communication with the policy and wider user community, primarily through a series of ESRC funded public seminars and workshops. One outcome of these activities has been the identification of a need to develop a user friendly, systematic and transparent accounting system that allows examination of the structure of pollution problems to be examined from a range of potential policy perspectives. Thus a key aim of this Climate Change Leadership Fellowship has been the development of a basic pollution accounting framework, based on the input-output (IO) methodology now widely adopted in both the academic literature and the policy advisory communities, and applied here to the case of CO2. This research has involved collaboration with colleagues at the Universities of Stirling, Strathclyde, Cardiff, Surrey, West Virginia and also at the OECD, the Stockholm Environment Institute and the Scottish Government, a number of whom are among the co-authors of this paper. The purpose of this paper is to present the IO pollution accounting tool developed under the Fellowship, with case studies of carbon dioxide emissions at the UK national and Scottish regional levels. It is important to note that the development of the accounting tool relies on data for a single year (2004), some of which has had to be estimated in the absence of official statistics (such as UK IO tables in the analytical format). If there is a need to conduct pollution accounting on a regular basis, to form the basis for official indicators of sustainability, public investment in appropriate data provision will be a necessity.

2. Two ways to account for carbon generation

In recognition of the problems posed by failing to prevent climate change, an international agreement was reached in 1997 in Kyoto on reducing greenhouse gas emissions, particularly CO2. However, more than a decade later a number of issues hindering the reduction of emissions have yet to be resolved. Major challenges still remain in securing the cooperation of all nations and in designing and delivering effective (and efficient) collective action within and between nations. One crucial issue impacting on unilateral attempts to fulfil national emissions reductions targets under the Kyoto Protocol is the impact of international trade on any one country's domestic emissions generation. The basic problem is that the generation of emissions in producing goods and services to meet export demand is charged to the producing nation's emissions account. That is, pollution generation in any one country is partly driven by consuming activities in others.

Munksgaard and Pedersen (2001) highlight this issue in distinguishing between a 'production accounting principle' and a 'consumption accounting principle' in considering the structure of pollution problems. The former, which we shall label PAP, focuses on emissions produced within the geographical boundaries of the national economy. This is what is accounted for, and what individual national governments are responsible for reducing, under the Kyoto Protocol. In contrast, the latter, which we shall label CAP, focuses on emissions produced globally to meet consumption demand within the national economy. This is what increasingly popular measures such as carbon footprints attempt to measure, and what many people regard as more appropriate, given that human consumption decisions are commonly considered to lie at the heart of the climate change problem. In a closed economy, with no trade

in goods and services, emissions accounts constructed under the production and consumption accounting principles would be equal (by definition). However, where there is trade and pollution is embodied in that trade through emissions generated in one region or nation to meet consumption demand in another, these need not be equal. A foreign 'trade balance' in pollution will exist in terms of the difference between total emissions estimated on the basis of the production and consumption accounting principles, or more simply, the difference between the pollution embodied in exports and the pollution embodied in imports.

Thus, the question arises as to whether PAP and/or CAP measures should be used to monitor and track pollution generation at the individual country level and what, if anything, can be done about foreign 'trade balances' in pollution. In this paper we present the IO accounting tool developed as part of the ESRC CCLF to estimate CO2 emissions linked to economic activity for the UK and Scottish economies (in the accounting year of 2004) and consider what type of questions/issues can be addressed using PAP and CAP measures in each case.

3. Summary carbon (CO2 equivalent) Accounting Results for the UK and Scotland1

Our results suggest that in 2004 the 'carbon footprint' of UK consumption 813.5 tonnes of CO2 equivalent was significantly higher than the level of CO2 emissions generated within UK borders (643.8 million tonnes of CO2) – see Section 5 and Table 1 below for a more detailed analysis.[2] That is, UK CO2 generation is 26% higher under the CAP than under the PAP measure that is the basis of CO2 reduction targets under Kyoto. This implies that the UK 'imports sustainability' from its trade partners. This result might be expected in the case of an advanced economy where there has been a shift from domestic production of many manufactured goods towards a domestic focus on more service orientated activities with increasing imports of manufactured goods. However, it raises questions as to whether relying solely on PAP measures (as under the Kyoto Protocol targets) is then a good measure of the sustainability of the UK economy.

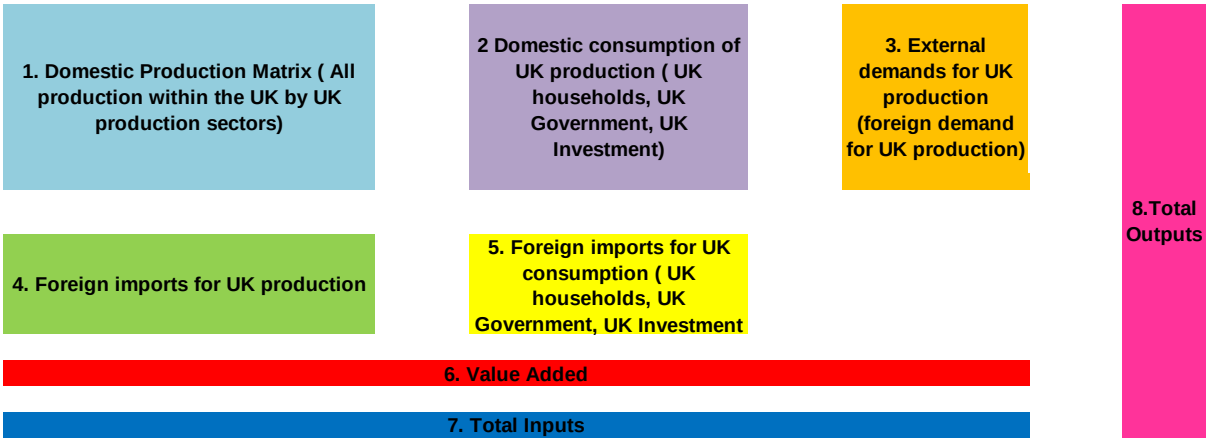
The Scottish results, on the other hand, are more complex. Here we find that Scotland also 'imports sustainability', but with a much larger difference between CO2 allocated under PAP (48.9 million tonnes of CO2 in 2004) and CAP (71.5 million tonnes of CO2) – i.e. a 46% increase as we move from measuring CO2 generated within Scotland, to considering Scotland's 'carbon' (CO2 equivalent) footprint. See Section 6 and Table 3 below. However, a key underlying determinant of Scotland's CO2 trade deficit, particularly with the rest of the UK is the fact that Scotland is a net exporter of electricity, which, given the (increasing) prevalence of renewable generation technologies in Scotland, means that the export side of its CO2 trade balance has a relatively low CO2 intensity and content. While of course there should be concern over the CO2 content of Scottish imports, the key implication that emerges from our results is that Scotland, by its choices in terms of choosing to foster renewable technologies in electricity generation, is helping to lower the carbon footprints of its trade partners, particularly the rest of the UK. This is illustrated by the fact that if we were to assume that UK average polluting technologies apply throughout the nation in the CO2 accounting exercise, not only is Scottish domestic CO2 generation (estimated under PAP) higher (at 66.7 million tonnes), we find that it would actually run a CO2 trade surplus with the rest of the UK, and its carbon footprint would only be 17% higher than its domestic CO2 generation, compared with the 26% difference at the UK level. Again, see Section 6 and Table 2 below for a more detailed analysis. Thus, it would seem that Scotland is 'punished' in CO2 trade balance terms by having adopted cleaner technologies in producing what are usually quite CO2 intensive exports. This is reflected in the fact that the actual Scottish carbon footprint is around 8% lower where Scottish renewable electricity generation technologies are incorporated in the calculation (Table 3) relative to what it would be if UK average technologies applied (Table 2).

Our carbon (in terms of CO2 equivalents) accounting results are detailed in Sections 5 and 6 below. However, reflecting points made in the introduction, the main question that we raise is whether the appropriate question in CO2 accounting terms is whether to adopt PAP or CAP measures when both measures are so clearly dependent on both consumption and technology decisions at home and abroad. Moreover, in the case of Scotland (and perhaps other UK regions), it raises questions as to the focus of indicators and targets within different regions that may play different roles in delivering on economic and environmental aspects of sustainable development objectives in the UK. This point links to the analysis in the second paper in this special issue of the Fraser Commentary, where we consider the case of Wales, a region of the UK characterised by relatively highly CO2 intensive production to meet export demand. There we consider how issues of jurisdictional control over polluting technologies impact on the arguments in favour of shifting focus towards consumption orientated measures.

4. The input-output accounting approach

Particularly in the environmental footprint literature (where focus is on accounting for emissions under the consumption accounting principle) input-output analysis has become

Figure 1: Schematic diagram of an Input-Output Table - The UK as an illustrative example



increasingly common as a technique to measure and allocate responsibility for emissions generation. See Wiedmann et al (2007), Wiedmann (2009), Turner et al, (2007) for reviews. This would seem a natural development, given that the focus of measures such as the carbon footprint is to capture the total (direct plus indirect) resource use embodied in final consumption in an economy. Input-output analysis is based around a set of sectorally disaggregated economic accounts, where inputs to each industrial sector, and the subsequent uses of the output of those sectors, are separately identified. Therefore, by the use of straightforward mathematical routines, the interdependence of different activities can be quantified, and all direct, indirect and, where appropriate, induced, resource use embodied within consumption can be tracked. This is commonly referred to as IO multiplier analysis[3].

Ideally, a multi-region input-output method that incorporates multi-lateral trade will be used to account for emissions under the production and consumption accounting principles and to determine pollution trade balances. However, this effectively requires a world environmental input-output table. While several projects are underway around the world to construct such a framework (e.g. the World Input-Output Database project[4]) an appropriate one for UK regional and national analysis is not currently available. Moreover, as indicated above, a frequently stated concern at public events run as part of the CCLF project relates to a need to begin with a simple, transparent framework, that relies as much as possible on currently available rather than estimated data (given that the latter are commonly quite 'black box' in nature, largely due to the complexity of the estimation methods). Therefore, one of our objectives in the CCLF project has been to develop a simple IO framework, which, while less comprehensive in nature (for example, not incorporating international feedback effects where imports to country X from country Y may require exports from X as intermediate inputs to production Y) allow a standardised accounting framework to be built up in stages that can be clearly explained to practitioners and users of accounting outputs. A central aim of the current paper is to provide a non-technical overview of the IO tool developed and used here.

Input output (IO) tables are national balance sheets showing the value of all goods flows between production sectors in an economy and final demand groups over the period of a year. They are an example of single entry booking-keeping, where a sale (output) in one sector is simultaneously recorded as a purchase (input) in another. Where extended to include environmental data, such as emissions generated in production, the IO system can be used to account for emissions generation where both the quantities produced and the associated emissions can be accounted for. Figure 1 shows a schematic IO table where the components of each section have been highlighted in a series of numbered blocks

In an actual IO table, each block would be a series of columns and rows representing the inter-sectoral flows of goods and services between production sectors, primary inputs and sales to final consumers in value terms.. It is important to note that where an IO table is reported in the analytical format required for multiplier analysis, sectoral level entries in Block 7, 'Total Inputs', and Block 8 ,'Total Outputs', must be equal.

Breaking the IO table into the blocks allows for an easy explanation of each IO table section in turn:-

Block 1 represents all production in the UK and accounts for sectors purchasing from other sectors within the UK economy.

Block 2 represents UK demands, which includes all UK households, government and capital formation demands.

The assumption with the conventional IO framework is that demand drives supply, so it is the demand groups within an economy that are responsible for the production sector producing a given level of output.

Block 3 represents the external demands, which include all the foreign producers and consumers that buy UK goods and services (export demands).

Block 4 represents purchases by UK producers from other countries to make UK goods and services. This can be thought of as UK producers buying parts for their own production. Note that in standard IO tables presented as part of national accounts, Block 4 would normally be represented as a single row showing the total value of imports to each production sector and final consumer. Here, and in the analysis that follows, we are grateful to colleagues at the Scottish Government and the Stockholm Environment Institute for assistance in identifying matrices for Scotland and the UK respectively where imports are broken down by commodity as well as by user. The same applies to Block 5.

Block 5 represents the goods and services UK consumers buy from abroad. All foreign goods that we see in UK shops would be included in this part of the table.

Block 6 represents payments to labour, profits and taxes, which are the value added components of the economy.

Blocks 7 and 8 represent total inputs (the sum of all the columns) and total outputs (the sum of all the rows) respectively. In an analytical IO table the respective input and output entries will be equal for each individual production sector.

So, which blocks do we consider for pollution generated under PAP?

Pollution generated under PAP (the production accounting principle) – the focus of Kyoto Protocol targets - takes into consideration pollution generated within the borders of the economy under study, whether this is to meet domestic or foreign (export) demand. This will equate to the sum of pollution directly generated in domestic production and directly by final consumers (most usually households, for example in burning gas in central heating systems or petrol in cars). Referring to the IO framework above, all pollution generated in production (Block 1) is attributable to (driven by) the final demands for domestic outputs in Blocks 2 and 3. Thus, as one of the components of final demand for a local economy, the external demand in Block 3 is included as a driver of domestic pollution generation. Thus PAP is considered by focussing solely on activity in Blocks 1 to 3, where Blocks 2 and 3 are responsible for the pollution generated in Block 1 (as well as any direct pollution generation within the economy under study by final consumers, which will generally only apply to Block 2 (unless tourists, external consumers who consume within the target economy are separately identified). Blocks 4 and 5, on the other hand, do not come into the PAP calculation. Thus, the PAP calculation allows us to look at emissions embodied in exports but it does not consider the other side of the pollution trade balance relationship; that is pollution embodied in imports.

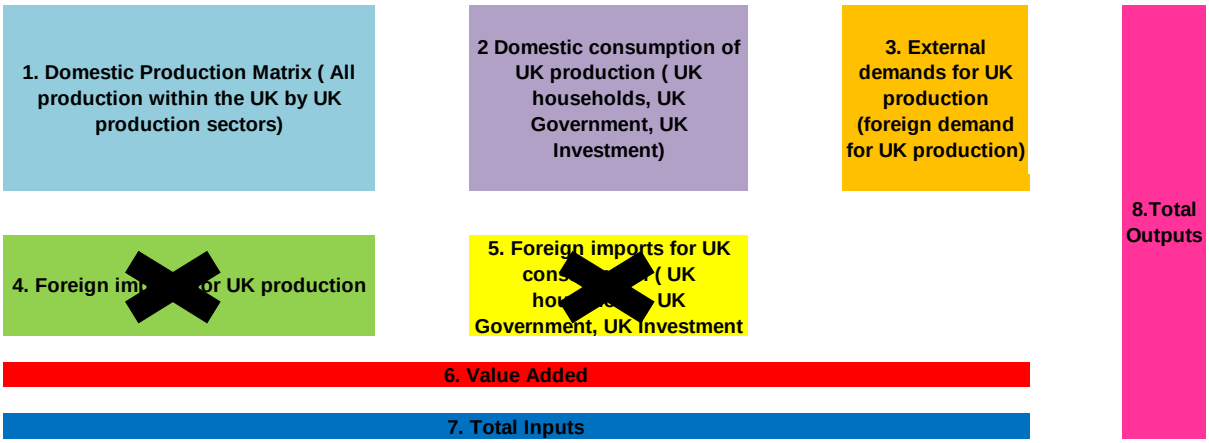
What about pollution generated under CAP?

A CAP measurement (such as a carbon footprint), on the other hand, does take account of pollution embodied in imports. However, if we move to a CAP measure we no longer consider Block 3 (external demand) as this becomes part of another nation's (or region's) footprint. What this means is that we now include the goods that domestic producers and consumers buy from abroad, which are recorded in Blocks 4 and 5. This is illustrated in Figure 3. Measures under the CAP would be the sum of pollution generated in Block 1 to meet Block 2 demands, as well as the sum of the pollution generated in Blocks 4 and 5 to meet the demand requirements of Blocks 1 and 2. However, since demands in Block 1 and 4 are intermediate demands, all pollution embodied in imports are ultimately attributed, along with domestic pollution generation, to the domestic final consumers in Block 2. In short, the CAP calculation gives us the sum of all pollution generated to allow the demands of domestic final consumers to be met, whether this pollution is generated at home or abroad.

The problem of finding economic and pollution data for CAP measures

As noted above, it has been possible to access data to populate the different blocks identified in Figures 1-3 above. However, there is a problem in that commodities produced in different countries will have different pollution profiles (reflecting different production methods). One issue that should be considered is that pollution generated in foreign production will depend on the production technology decisions made in each individual country and each production sector therein. Concerns surrounding the methodologies employed for the estimation of country specific pollution can be addressed using the Domestic Technology Assumption (DTA). The DTA approach is sometimes adopted in the literature (see Druckman et al, 2008), as a way of overcoming a lack of available pollution data for other countries. What the DTA suggests is that by applying the same production technologies and therefore pollution intensity to foreign production of the commodities reported in Blocks 4 and 5 as is applied to domestic production (in Block 1) we are able to calculate a consumption measure based on the technology choices of the home economy. However, if the economy under study is (on aggregate) more pollution intensive than the countries it imports from this will lead to an overestimated footprint

Figure 2: Components of the IO table used for calculation of a PAP measure



measure, and vice versa (of course this will depend on the mix of goods and services consumed, some of which will be more and some less pollution intensive). In the second paper in this special issue, it is also argued that the DTA method may be appropriate if we wish to focus on technology decisions that fall under the jurisdictional control of domestic policymakers. In this way, the DTA method is argued to consider the footprint from the perspective of the savings made by not producing at home, rather than the costs abroad.

A second approach that we have applied in the examples that follow in Sections 5 and 6 (and in the summary in Section 3 above) is to relax the DTA assumption. When and if actual country specific data do become available, the DTA assumption can be relaxed and the actual data inserted for whatever countries and/or sectors this is available for. With the assistance of our colleagues at the OECD we have been able to split out Blocks 4 and 5 to identify imports from 13 different regions in the rest of the world (see Appendix 1), and to assign corresponding pollution intensities. Thus, we are able to report the CAP calculations first making the DTA assumption then relaxing it. The difference in the two calculations solely reflects differences in polluting technologies between the economy under study and the countries that it imports from (given that the scale of activity is the same in both calculations).

5. Case study 1: the UK national economy

To demonstrate the use of the IO tool we consider the case of the UK in 2004[6]. The results of the PAP calculation (CO2 generated within UK borders in 2004) and the CAP calculation (CO2 attributable to UK final consumption in 2004), with the latter reported first under the DTA assumption then with this relaxed.

The top row of Table 1 shows the headline figures. Under PAP, 643.8 million tonnes of CO2 (equivalent) were produced in the UK in 2004. The second entry in the PAP column shows that just over 25% of this (163.7 million tonnes of CO2) were directly generated in the household sector. However, reading down the column we see how the remaining 480.1 million tonnes directly generated in UK

Figure 3: Components of the IO table used for calculation of a CAP measure

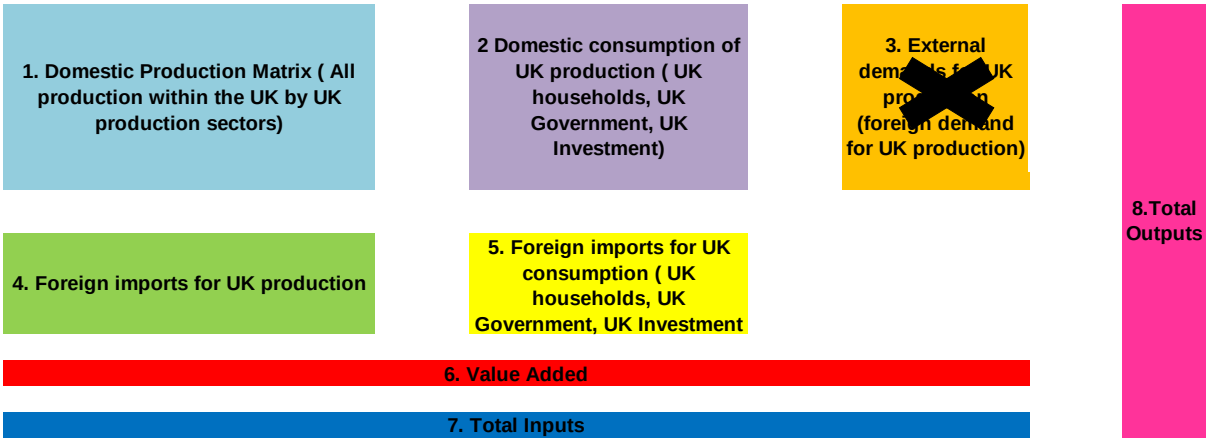


Table 1: UK CO2 generation (2004) under different IO accounting principles

	CO2 generated within UK - PAP	UK 'carbon' (CO2) footprint - CAP (DTA)	UK 'carbon' (CO2) footprint - CAP (relax DTA)
Total CO2 attributed (tonnes)	**643,806,114**	**712,677,329**	**813,536,304**
CO2 supported by UK final consumption			
Domestic (UK) CO2 generation:			
Directly generated (households)	163,676,326	163,676,326	163,676,326
Indirect - generated in UK production sectors, supported by:			
household final consumption	235,930,577	235,930,577	235,930,577
government final consumption	50,032,572	50,032,572	50,032,572
capital formation	41,479,167	41,479,167	41,479,167
	491,118,642	**491,118,642**	**491,118,642**
Indirect CO2 embodied in imports supported by :			
household final consumption		149,133,532	232,247,838
government final consumption		22,242,094	31,905,450
capital formation		50,183,062	58,264,375
		221,558,688	**322,417,662**
CO2 supported by external demands for UK production	**152,687,472**		
Implied CO2 trade balance (deficit):			
CO2 embodied in exports minus CO2 embodied in imports (CO2 generation under PAP minus CAP)		**(68,871,216)**	**(169,730,190)**

production are indirectly attributable to domestic and external demands in Blocks 2 and 3 (respectively) of the IO schematics above. We see that just under 24% of UK CO2 was generated to meet external demands. Thus, the figure of 152.7million tonnes attributable to export demands is excluded from the carbon (CO2) footprint calculations in the last two columns. However, in its place (domestic emissions driven by domestic consumption are common to both the PAP and CAP calculations) we must bring in a measure of the CO2 embodied in imports.

In the CAP (DTA) calculation, the CO2 embodied in imports at 221.6 million tonnes exceeds the CO2 embodied in exports with the implication that the estimated carbon footprint, 712.7 tonnes of CO2 exceeds UK domestic emissions under PAP. Thus, regardless of the direction of the goods and services trade balance, the UK runs a CO2 trade deficit of 68.9 million tonnes and is effectively importing sustainability. Now, in 2004 the UK did run a trade deficit with imports exceeding exports by just over 12%. However, in the CAP (DTA) column of Table 1, the CO2 embodied in imports exceeds the CO2 embodied in exports by 45%. Thus, even assuming no differences in polluting technologies, this tells us that the UK imported more CO2 intensive goods and services than it exported. It is possible to speculate, then, that if the UK were not able to trade, its CO2 emissions under PAP would be much higher, and its ability to meet its targets under the Kyoto Protocol negatively affected.

However, if we do take into account differences in polluting technologies, by relaxing the DTA assumption in the final column of Table 1, the picture is much worse: the UK carbon (CO2 equivalent) footprint rises by 14% from 712.7 million tonnes of CO2 to 813.5 million tonnes. Underlying this is the huge (almost 46%) increase in the CO2 embodied in imports from 221.6 to 322.4 million tonnes. As explained above, this increase is entirely due to the fact we are taking differences in polluting technologies in the source country into account. This of course raises the question, considered in more detail in the second paper in this issue) as to what UK consumers and/or policymakers could do about this increase. We may choose how much to consume but what control do we have over how it is consumed? Of course, the same question could be raised in terms of UK consumers purchasing from UK producers. The key difference is that UK policymakers have some control over both the latter, but it is not clear that they could exert much, if any, impact on the technology decisions of producers in other countries. On the other hand, if CO2 accounting exercises such as this one reveal CO2 ‘hot spots’ in the supply chain, consumers may wish to change their consumption decisions and purchase from cleaner producers in cleaner countries. However, this would have implications for international trade and development. One solution may be to develop carbon

accounting practices in order to assign levels of shared responsibility (and this has been explored in the literature; both in terms of a 'sharing' of the domestic national emissions balance between producers and consumers (Andrew & Forgie (2008), Lenzen et al (2007)) and in terms of sharing the emissions embodied in trade (Peters, 2008)); the former measure provides a different way of thinking about domestic responsibility for the national emissions balance, but in the case of the latter approach at least, it is not clear what additional value this type of approach would add.

The CAP and CO2 trade balance results reported for the UK in this study show a significant difference to those found in previous studies. Druckman and Jackson (2008) found that CO2 estimated under the CAP measure was 19% higher than under the PAP measure in 2004 using a quasi-multi-regional input-output model (QMRIO). Similarly Wiedmann et al (2008) estimated the difference to be 21% using a multi-regional input-output model (MRIO). In this study we find the CO2 estimated under the CAP measure for 2004 are 26% higher than under the PAP measure. While use of a fuller interregional framework allows additional effects such as interregional feedback effects and multiplier effects in source countries based on IO tables for those countries (rather than the UK combined use matrix approach used here), we would conclude that the OECD data used to estimate the pollution content of imports here are producing higher estimates than those estimated using GTAP data in the Druckman and Jackson (2008) and Wiedmann et al (2008) studies.

Finally, note that, while we focus on the headline results in this text, the IO approach builds these up from the sectoral level. For the interested reader we have included in Appendix 2 a detailed explanation of sectoral level effects building up the share of the UK Food and Drink sector (as an example) in the overall PAP and CAP calculations.

6. Case study 2: the Scottish economy

Next, we consider the case of Scotland within the UK economy in 2004. While corresponding IO tables for Scotland (augmented with matrices of imports to Scottish production and final consumption from the rest of the UK and rest of the world respectively), do not currently employ the Scottish CO2 intensity of the different production sectors as this is not publicly available. Therefore, in the first instance we apply the UK average CO2 intensities used in the UK analyses above. The results of the PAP calculation (CO2 generated within Scottish borders in 2004) and the CAP calculation (CO2 attributable to Scottish final consumption in 2004), with the latter reported first under the DTA assumption then with this relaxed, are shown in Table 2.

As in the UK case, CO2 emissions attributed to Scotland are considerably higher under CAP than PAP. The first column of Table 2 reports Scottish CO2 under PAP in 2004 at 66.7 million tonnes. In the first instance, where we use the DTA assumption in the CAP estimate the increase is only 3.5% to 69 million tonnes of CO2. However, when we relax the DTA assumption, introducing the OECD data on sources of imports and corresponding CO2 intensities, CAP is 16.6% larger than PAP at 77.8 million tonnes of CO2.

However, perhaps the most interesting point here is that while Scotland runs an overall CO2 trade deficit (importing more CO2 than it exports), the opposite is true in terms of Scottish trade with the rest of the UK, where CO2 embodied in exports (35 million tonnes) is considerably higher than CO2 embodied in imports from the rest of the UK (19.8 million tonnes), with the implication that Scotland runs a 7.8 million tonne CO2 trade surplus with the rest of the UK.

This is an issue that was explored previously by McGregor et al (2008) , and, as in that analysis, the main explanation for this relationship is the fact that Scotland is a net exporter of electricity to the rest of the UK. However, what the analysis in Table 2 fails to reflect is the fact that, with her higher capacity for electricity generation from renewable sources, Scotland is actually a relatively clean producer of electricity, with the implication that it may be better for the UK (in CO2 generation terms at least) that this relationship exists. In order to explore further, it is necessary to introduce more accurate information on the CO2 intensity of Scottish electricity production, rather than relying on the UK average as we have done in Table 2.

Table 3 compares the results of the PAP and CAP (with DTA relaxed) CO2 accounting exercise for Scotland if we introduce as single change. This is the introduction of a Scottish-specific CO2 intensity for the 'Electricity production and distribution' (IOC 38) sector. This was provided by colleagues at Scottish Government. It reflects the higher dependence on renewable technologies in Scotland and, at 2616 tonnes of CO2 per £1million of output is around half the size of the UK average (5430 tonnes per £1million). The point of this exercise is to examine the impact of reducing the pollution intensity of this key polluting sector of the Scottish economy on the total CO2 emissions balance.

The first column in Table 3 shows the estimated emissions that are generated so satisfy each type of final demand (in Blocks 2 and 3 in the schematics in Figures 1 and 2) under PAP. Here we can see that the total CO2 generated within Scottish (in 2004) under PAP at 48.9million tonnes of CO2 equivalent is almost 27% less than the figure of 66.7 million tonnes reported in Table 2 (see columns 2 and 4 in Table 3 for percentage comparisons). This difference is entirely due to the replacement of the UK CO2 intensity with a Scottish-specific one in the electricity sector only. As in Table 2, total CO2 under PAP is split between domestic demands, which support 25.5 million tonnes, or 52% of CO2 generated. The

Table 2: Scottish CO2 generation (2004) under different IO accounting principles

UK average CO2 intensities applied to all Scottish and UK activities	CO2 generated within Scot - PAP	Scot 'carbon' (CO2) footprint - CAP (DTA)	Scot 'carbon' (CO2) footprint - CAP (relax DTA)
Total CO2 attributed (tonnes)	**66,711,016**	**69,021,834**	**77,759,681**
CO2 supported by Scottish final consumption			
Domestic (Scottish) CO2 generation:			
Directly generated (households)	11,329,373	11,329,373	11,329,373
Indirect - generated in Scottish production sectors, supported by:			
household final consumption	15,288,628	15,288,628	15,288,628
government final consumption	3,630,530	3,630,530	3,630,530
capital formation	1,479,033	1,479,033	1,479,033
	31,727,564	**31,727,564**	**31,727,564**
Indirect CO2 embodied in imports supported by :			
Imports from the rest of the UK			
household final consumption		15,116,687	15,116,687
government final consumption		1,912,391	1,912,391
capital formation		2,753,704	2,753,704
		19,782,783	**19,782,783**
Imports from the rest of the world			
household final consumption		12,352,490	19,683,011
government final consumption		2,078,502	2,840,354
capital formation		3,080,495	3,725,969
		17,511,487	**26,249,334**
Total emissions embodied in imports		**37,294,270**	**46,032,117**
CO2 supported by external demands for Scotland production			
Demand from the rest of the UK	**27,584,391**		
Demand from the rest of the world	**7,399,060**		
Total	**34,983,452**		
Implied CO2 Trade Balance (Deficit):			
CO2 embodied in exports minus CO2 embodied in imports			
(CO2 generation under PAP minus CAP)			
Rest of the UK		**7,801,608**	**7,801,608**
Rest of the world		**-10,112,427**	**-18,850,274**
TOTAL		**-2,310,819**	**-11,048,665**

remainder is attributable to export demands. However, the amount of CO2 attributable to export demand from the rest of the UK, at 17.6 million tonnes, is considerably (36%) lower than the 27.6 million tonnes in Table 2. Again, this is entirely due to the correction to better reflect Scottish electricity generation from less CO2-intensive renewable sources.

However, the key point to note is that the impact of this is to change the direction of the CO2 trade balance relationship between Scotland and the rest of the UK, with a 2.1 million tonne deficit replacing the 7.8 million tonne surplus in Table 2. Overall, the Scottish CO2 footprint, reported in the third column (with DTA relaxed) does fall by 8% from 77.8 million tonnes of CO2 in Table 2 to 71.5 million tonnes in Table 3 with this more accurate representation of real conditions. Note that this is entirely due to the reduction in CO2 generated within Scotland to support Scottish demands as the CO2 embodied in imports is not affected by the adjustment to reflect the CO2 intensity of Scottish electricity production. Thus, the reduction in CAP in moving from Table 2 to Table 3 is smaller than that in PAP, which takes into account the reduction in CO2 generation to support external demands also.

Table 3: Impact of Scottish renewables technologies on Scottish CO2 generation (2004)

Scottish-specific CO2 intensity for electricity generation (UK average CO2 intensities applied to all other Scottish and RUK

	CO2 generated within Scot - PAP	Change relative to Table 2, Column 1	Scot 'carbon' (CO2) footprint - CAP (relax DTA)	Change relative to Table 2, Column 3
Total CO2 attributed (tonnes)	**48,946,902**	**-26.63%**	**71,514,117**	**-8.03%**
CO2 supported by Scottish final consumption				
Domestic (Scottish) CO2 generation:				
Directly generated (households)	11,329,373	0.00%	11,329,373	0.00%
Indirect - generated in Scottish production sectors, supported by:				
household final consumption	10,029,030	-34.40%	10,029,030	-34.40%
government final consumption	2,875,185	-20.81%	2,875,185	-20.81%
capital formation	1,248,411	-15.59%	1,248,411	-15.59%
	25,482,000	**-19.68%**	**25,482,000**	**-19.68%**
Indirect CO2 embodied in imports supported by :				
Imports from the rest of the UK				
household final consumption			15,116,687	0.00%
government final consumption			1,912,391	0.00%
capital formation			2,753,704	0.00%
			19,782,783	**0.00%**
Imports from the rest of the world				
household final consumption			19,683,011	0.00%
government final consumption			2,840,354	0.00%
capital formation			3,725,969	0.00%
			26,249,334	**0.00%**
Total emissions embodied in imports			**46,032,117**	**0.00%**
CO2 supported by external demands for Scotland production				
Demand from the rest of the UK	**17,644,815**	**-36.03%**		
Demand from the rest of the world	**5,820,087**	**-21.34%**		
Total	**23,464,902**	**-32.93%**		
Implied CO2 Trade Balance (Deficit):				
CO2 embodied in exports minus CO2 embodied in imports				
(CO2 generation under PAP minus CAP)				
Rest of the UK			**-2,137,968**	**-127.40%**
Rest of the world			**-20,429,247**	**8.38%**
TOTAL			**-22,567,215**	**104.25%**

The key point is that on the face of it, from a consumption accounting perspective, Scotland does not seem to perform quite so well in Table 3, with a much bigger wedge between PAP and CAP, reflected in the larger net CO2 trade deficit. However, this is not due to higher CO2 generation to meet Scottish consumption (CAP falls between Tables 2 and 3). Rather, it is due to Scotland using cleaner technologies in its production to meet export demand. Surely this is a good thing? As well as reducing Scottish PAP and CAP emissions, it will reduce the carbon footprint of trade partners, primarily the rest of the UK who buy this cleaner electricity, and means a net reduction in total global CO2 emissions. This is the climate change problem that policy aims to address. Indeed, the Scottish results contrast with the Welsh case examined in the second paper in this special issue, where the relatively high CO2 intensity of Welsh production to meet export demands leads to it performing better on CAP than it does on PAP.

Thus, the conclusion that we draw here is that a CAP measure on its own is insufficient to consider the carbon and climate change implications of activity in an open economy. That is, the results of the analyses presented here would seem to raise the issue of whether the appropriate question in carbon accounting terms is whether to adopt PAP or CAP measures when both measures are so clearly dependent on both consumption and technology decisions at home and abroad. Rather, some mix of accounting principles would seem appropriate and, within that, considerations of issues such as shared responsibility with respect to what aspects of carbon generation can and should be considered the responsibility of producers and consumers will be relevant, particularly where these are located in different countries.

7. Conclusions

A key point highlighted in the results reported here is that if we are focussed on a CAP measure, then we are completely unconcerned with any reduction in the emissions embodied in what we export, since under CAP this is the responsibility of consumers in another jurisdiction. Rather, what we are interested in under CAP is reducing the emissions embodied in what we consume, and so we may want to focus on sectors where the reduction in their emissions intensity has large impacts in reducing the emissions embodied in domestic consumption, whether the pollution involved occurs at home or abroad. The strategy employed to meet any target set must take account of what the target itself does and does not cover. For example, pursuing a CAP target may lead to the potentially paradoxical situation where domestic governments are not incentivised by this target to constrain domestic pollution where this is generated to serve foreign demands.

It is important to note that we are not trying to suggest that there is little merit in consumption based targets. Rather, given the interest in the policy community in CAP based measures, we are taking this opportunity to pose questions such as why CAP rather than PAP targets are being promoted, what impacts it is that policymakers are concerned about, and what are the tradeoffs involved in the variety of measures that are available. We have argued elsewhere (see Jensen et al, 2010, and the second paper in this special issue) that there are other probing questions that need to be asked of policymakers pursuing footprint measures. For example, how useful is a CAP based measure when domestic policymakers have little say (and no jurisdiction) over the technologies employed to produce imported goods? While there are obvious and well known drawbacks to the use of PAP measures, CAP measures also have their problems. The difficulties involved in PAP and CAP measures are not insurmountable, but they do need to be discussed and understood.

More generally, a core aim of this paper has been to introduce a carbon accounting tool based on IO techniques. The IO tool presented in this paper maintains the rigour of the traditional IO framework but shows how the IO has been developed into a user friendly tool that will allow the policy community and stakeholders to begin addressing numerous policy concerns and questions, hopefully with more interaction with a more transparent empirical tool. We hope that we have managed to present our analyses in an easy to understand format, with the aim of facilitating deeper comprehension about sustainable issues and ensure that the added value from use of IO as an accounting tool is obtained. Additionally, with IO tables being increasingly regularly reported at a regional and national level, the tool could be a first step towards a standardised measure across countries and regions, which would help address policy concerns that are bigger than the national level.

Where the benefits of the IO tool for pollution accounting are true for all interested users, there are a few benefits that are especially valuable to the policy community. A few of these are highlighted below:

- Allow the evaluation of the success of policy goals through the creation of indicators of resource sustainability;
- Identify sectors or areas of the economy that could benefit from policy intervention;
- Provide a better understanding of supply chains and where major impacts occur within them, and
- Provide insight into the flows of such pollutants or resources embodied in products and services between the UK, the EU and the wider world.

We welcome feedback from all potential users of the type of tool we have developed. Please contact karen.turner@str.ac.uk

Appendix 1: Use of OECD data to determine the pollution content of imports

The OECD maintains detailed databases on international trade flows by country, and has recently added data on country and industry specific CO2 intensities, derived from underlying energy usages to this database. Working with our co-author Norihiko Yamano from the OECD, the fellowship team have been able to access to these data, and this paper reflects the first application of these data. This appendix is intended to give an overview of both the data themselves, and our specific application to create our weighted pollution intensities that we used here for the carbon footprint calculations for the UK and Scotland.

The underlying data comprise import tables using the International Standard Industrial Classification (revision 3)[7] system. We started by extracting UK import matrixes for trade with all available countries. While all the data were in a consistent currency (US Dollars) they were not in a consistent year, and were adjusted using country specific inflation/deflation factors from the World Bank[9]. Clearly this

approach is vulnerable to criticism on the basis of currency fluctuations affecting the value of a dollar across time, but the approach taken did not generally require significant adjustment across years, and we think that our approach here represents a pragmatic approach to this problem. Having examined the range of countries that were covered by these data, we decided upon a regional classification approach, and aggregated the world (and our data) into 14 regions. These were:

1. United Kingdom
2. United States
3. Canada
4. Germany
5. France
6. Rest of OECD Europe and EU27
7. Russia
8. China
9. Developed Asia and Oceania
10. Developing Asia
11. Australia and New Zealand
12. Central and south America
13. OPEC countries (excluding Indonesia)
14. Rest of the World

Also, we had to decide on a sectoral aggregation across the economic sectors that can be mapped to a classification that is consistent with both the UK input-output data and also the environmental data available from OECD. To this end, we settled upon a 45 sector aggregation which is contained in Table A1 below. This table shows the mapping from the full 123 SIC used in the full input-output case to the 45 sector aggregation used here in this analysis. Our main purpose here is to establish what percentage of UK imports of sector i's output are imported from region n. To this end, and using the consistent and aggregated (both in terms of regions and sectors) imports matrixes we worked out the share of total UK imports that were contributed (at the sectoral level) by each region.

Due to limited data on imports we had to estimate these across sectors/commodities 28-34 and 34-45 using a constant import share for each region. In the case of sectors 28-34 and 35-45, we believed that aggregating the available data across sectors for each region and estimating import shares based on them, provided the most consistent approach, and prevented the absence of data on imports from one sector leading to unusual and unexplainable results. So in effect (remembering principal purpose in using the OECD trade data is simply to obtain the share of imports from each sector contributed by each region) what our assumptions here are doing is to use proxy shares that we consider reasonable to fill the data gaps that exist. We do not believe that the assumptions that are outlined above and that we made in constructing our data compromise the integrity or usefulness of our approach. Using these data, we proceeded to estimate these sectoral level shares and create the share matrix [SM]. In a similar fashion, with no import data for sectors 26 and 27 (collection purification and distribution of water, and construction respectively) we made a decision to assume a split in import propensities for these sectors across the France, Germany and the rest of OECD Europe and EU27 regions.

Having now obtained our import share matrix (the percentage of imports of each foregin sector/commodity output imported to the UK from each region) we proceed to estimate regional sectoral CO2 intensities (tonnes of CO2 per monetary unit of output). We use the OECD CO2 emissions from fuel combustion by sector as the basis for this intensity calculation, by first aggregating into our 14 regions the total CO2 emissions from fuel combustion by sector. Having done this, we had a matrix of total sectoral pollution which we divided by the matrix of regionally aggregated total sectoral output. In other words, we divided the total pollution generated in each sector in each region by the total of regional sectoral output for each sector from the OECD input-output data that we adjusted to be year

Table A.1

123 sectors	Description	45 sector	123 sectors	Description	45 sector	123 sectors	Description	45 sector
1	Agriculture	1	45	Chemical Products nes	10	89	Distribution and Motor Repair, etc	28
2	Forestry	1	46	Man-Made Fibres	10	90	Wholesale Distribution	28
3	Fishing	1	47	Rubber Products	11	91	Retail Distribution	28
4	Coal Extraction etc	2	48	Plastic Products	11	92	Hotels, Catering, Pubs, etc	29
5	Extraction - Oil and Gas	3	49	Glass and Glass Products	12	93	Railways	30
6	Extraction - Metal Ores	4	50	Ceramic Goods	12	94	Other Land Transport	30
7	Other Mining and Quarrying	4	51	Structural Clay Products	12	95	Water Transport	31
8	Meat Processing	5	52	Cement, Lime and Plaster	12	96	Air Transport	32
9	Fish and Fruit Processing	5	53	Articles of Concrete etc	12	97	Transport Services	33
10	Oils and Fats	5	54	Iron and Steel	13	98	Postal Services	34
11	Dairy Products	5	55	Non-ferrous Metals	13	99	Telecommunications	34
12	Grain Milling and Starch	5	56	Metal Castings	13	100	Banking & other financial institutions	35
13	Animal Feeding Stuffs	5	57	Structural Metal Products	14	101	Insurance and Pension Funds	35
14	Bread, Biscuits, etc	5	58	Tanks, reservoirs and containers of metal; manufacture of central heating radiators and boilers; manufacture of steam generators	14	102	Auxiliary Financial Services nes and auxiliary to insurance	35
15	Sugar	5	59	Forging, pressing, stamping and roll forming of metal; powder metallurgy; treatment and coating of metals	14	103	Owning and Dealing in Real Estate	36
16	Confectionery	5	60	Cutlery, tools and general hardware	14	104	Letting of Dwellings	36
17	Miscellaneous Foods	5	61	Metal Goods	14	105	Estate Agent Activities	36
18	Spirits and Wines, etc	5	62	Mech Power Transmission Equipment	15	106	Renting of Machinery	37
19	Soft Drinks	5	63	General Purpose Machinery	15	107	Computing Services	38
20	Tobacco	5	64	Agricultural Machinery	15	108	Research and Development	39
21	Textile Fibres	6	65	Machine Tools	15	109	Legal Activities	40
22	Textile Weaving	6	66	Special Purpose Machinery	15	110	Accountancy Services	40
23	Textile Finishing	6	67	Weapons and Ammunition	15	111	Market Research	40
24	Made-up Textiles	6	68	Domestic Appliances nes	15	112	Architectural etc Activities	40
25	Carpets and Rugs	6	69	Office Machinery	16	113	Advertising	40
26	Other Textiles	6	70	Electric Motors and Generators	17	114	Other Business Services	40
27	Knitted Goods	6	71	Insulated Wire and Cable	17	115	Public Administration	41
28	Wearing Apparel	6	72	Electrical Equipment nes	17	116	Education	42
29	Leather Tanning	6	73	Electronic Components	18	117	Health and Veterinary Services	43
30	Footwear	6	74	Transmitters for TV, Radio and Phone	18	118	Social Work	44
31	Timber and Wood Products	7	75	Receivers for TV and Radio	18	119	Sanitary Services	44
32	Pulp, Paper and Board	8	76	Medical and Precision Instruments	19	120	Membership Organisations	44
33	Paper and Board Products	8	77	Motor Vehicles	20	121	Recreational Services	44
34	Printing and Publishing	8	78	Shipbuilding and Repair	21	122	Other Service Activities	44
35	Oil Process, Nuclear Fuel	9	79	Other Transport Equipment	21	123	Private Households with employed persons	45
36	Industrial Gases	10	80	Aircraft and Spacecraft	21			
37	Inorganic Chemicals	10	81	Furniture	22			
38	Organic Chemicals	10	82	Jewellery and Related Products	22			
39	Fertilisers	10	83	Sports Goods and Toys	22			
40	Synthetic Resins	10	84	Miscellaneous Manufacturing nes	22			
41	Pesticides	10	85	Electricity Production and Distribution	23			
42	Paints, Dyes, Printing Ink, etc	10	86	Gas; distribution of gaseous fuels through mains; steam and hot water supply	24+25			
43	Pharmaceuticals	10	87	Collection, purification and distribution of water	26			
44	Soap and Toilet Preperations	10	88	Construction	27			

consistent. This gives us a matrix of regional and sectoral pollution intensities [PI]. We use this matrix of regional and sectoral pollution intensities [PI] to construct our weighted output-pollution coefficient vector by multiplying the share matrix [SM] by the matrix of pollution intensities [PI]. This means that each element sMij (the share of total UK imports from sector i that are imported from region j) is multiplied by each element PIij (the pollution intensity of sector i in region j) which if we sum each row (i.e. for all i=1,...,n) gives us a weighted output-pollution coefficient based on the propensity to import from each sector in each region, taking account of the underlying pollution intensity of production in these sectors and in these regions.

Appendix 2: Working through a sectoral example for the UK

UK Food and Drink (IOC 8-19)

PAP

In 2004, the composite UK Food and Drink sector had a direct CO2 intensity of 151 tonnes of CO2 per £1million output produced. In 2004, direct emissions in the Food and Drink sector accounted for 1.46% of total UK CO2 generation under PAP (643, 806, 114 tonnes in Table 3). However, this does not take account of CO2 generation in other sectors of the UK economy (under PAP) supported by final demand for Food and Drink sector outputs. A standard Type I multiplier analysis (i.e. indirect linkages with other UK industries) using the UK IO tables tells us that for every £1million of final demand for Food and Drink, an additional £0.98million of output is (indirectly) required throughout the UK economy (i.e. the output multiplier is 1.98). The impact on the CO2 intensity of UK Food and Drink is even more significant. For every tonne of CO2 directly generated in the Food and Drink sector itself, another 2 tonnes are required throughout the UK economy. That is, the output-pollution multiplier (CO2 generated throughout the UK economy) is 462 tonnes tonnes of CO2 per £1million of final demand for Food and Drink output (compared to the direct intensity of 151 tonnes of CO2 per £1million of output produced). Taking these backward linkage effects into account, 2% of total UK pollution under PAP is accounted for by Food and Drink sector production to meet final demand accounts for.

A key determinant of the UK Food and Drink sector multiplier is purchases from the relatively CO2-intensive Agriculture sector (IOC 1). The UK Agriculture sector has a direct CO2 intensity of 285 tonnes per £1million output. Intermediate purchases from Agriculture accounted for 10% of total inputs to the Food and Drink sector in our accounting year of 2004, or 19% of intermediate purchases from other UK sectors. In addition, 31% of imports to the Food and Drink sector are also Agriculture commodities (produced outside the UK).

If we focus on the linkage between UK Food and Drink and the UK Agriculture sector in the first instance, the intermediate input requirement from the former to the latter, accounts for 6% of the output multiplier in the Food and Drink sector (noted above as 1.98), or 13% of the indirect effect (0.98). That is, for every £1million of final demand for Food and Drink commodity output, £0.12million of output is required in the UK Agriculture sector. However, due the relatively high CO2-intensity of the Agriculture sector (285 tonnes per £1million output), this equates to 36 tonnes of CO2 in Agriculture generated for every £1million of Food and Drink output. This is 8% of the total output-CO2 multiplier value for Food and Drink (462 tonnes of CO2 from above).

CAP

However, from a fuller CAP perspective, the composite commodity produced by the Food and Drink sector has a greater impact on the UK's carbon footprint. First of all, consider the impact of considering import-induced output and CO2 effects in the DTA CAP calculation in the second column of Table 3 (712, 677, 329 tonnes of CO2) – i.e. assuming that the direct CO2 intensities of production for the UK apply to all commodity production (imported or domestically produced) – where 3.64% of this total is attributable to UK final demand for Food and Drink. Continuing with the focus on the backward linkage with Agriculture, the global output multiplier effect in this sector rises from £0.12million to £0.21million for every £1million of final demand for UK Food and Drink. The additional output effect is on imports/production outside of the UK. The impact on the Agriculture component of the Food and Drink output-CO2 multiplier is even more significant, rising from 35.5 tonnes (per £1million) if we consider only CO2 generation within UK Agriculture to 60 tonnes if we consider the additional CO2 that the UK saves by not producing all the Agriculture requirements of its Food and Drink sector domestically.

However, if we relax the DTA assumption – i.e. taking into account the actual direct CO2-intensity of commodity production in exporting countries – the impact is even more dramatic. Output multiplier values are unchanged; however, output-CO2 multiplier values change to reflect the different CO2 intensities. In the case of the UK Food and Drink intermediate input requirements of Agriculture commodities, 94 tonnes of CO2 are required around the world for every £1million of final demand (or 90 grammes per £1). The increase of 34 relative to the 60 tonnes of CO2 under DTA is due to the higher CO2-intensity of agricultural production outside the UK.

The OECD data used to relax the DTA assumption here (see Appendix 1) tell us that Agriculture production is only less CO2 intensive than the UK in Germany, France and the region of Developed Asia and Oceana. However, imports from these areas only accounts for 10% of total UK imports of Agriculture commodities. That is, 90% of imports are sourced from regions/countries where Agriculture is more CO2-intensive than in the UK. This will be due to a combination of the composition of Agriculture activity in the

source region/country, as well as differences in technologies.

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Endnotes

[1]More detailed analyses follow in Sections 5 and 6. The purpose of this section is to summarise the key findings.

[2] Note that throughout the analysis here we use UK Environmental Accounts data that include emissions from UK aviation and shipping.

[3]Background information for multiplier analysis is available to download from the Scottish Government at: http://www.scotland.gov.uk/Topics/Statistics/Browse/Economy/Input-Output/Mulitipliers

[4]The World Input Output Database Project. Information available from: http://www.wiod.org/

[5]Here and in Figure 1 we discuss for the example of the UK but this could be done in the context of any region/nation under study.

[6]In the absence of a published UK IO table in the appropriate analytical form, a UK IO table for 2004 was derived from the published Supply and Use Tables. This was done under the ESRC CCLF project with advice and assistance from the Scottish Government IO team and the Stockholm Environmental Institute. The table – available to download at: http://www.strath.ac.uk/fraser/research/2004ukindustry-byindustryanalyticalinput-outputtables/ – is reported at the 123 sector level that is standard in UK IO accounting. However, the analysis reported here is based on a 68 sector breakdown that maps to the UK Environmental accounts. Of course it would be possible to apply the pollution intensities from this breakdown at the 123 sector level also. Web links to both the UK Supply and Use Tables and the UK Environmental Accounts from the ONS, are available in the references section below.

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Reconsidering the calculation and role of environmental footprints

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Introduction

Following the recent Copenhagen Climate Change conference, there has been discussion of the methods and underlying principles that inform climate change targets. Climate change targets following the Kyoto Protocol are broadly based on a production accounting principle (PAP). This approach focuses on emissions produced within given geographical boundaries. An alternative approach is a consumption accounting principle (CAP), where the focus is on emissions produced globally to meet consumption demand within the national (or regional) economy[1]. Increasingly popular environmental footprint measures, including ecological and carbon footprints, attempt to measure environmental impacts based on CAP methods. The perception that human consumption decisions lie at the heart of the climate change problem is the impetus driving pressure on policymakers for a more widespread use of CAP measures. At a global level of course, emissions accounted for under the production and consumption accounting principles would be equal. It is international trade that leads to differences in emissions under the two principles.

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This paper, the second in this special issue of the Fraser Commentary, examines how input-output accounting techniques may be applied to examine pollution generation under both of these accounting principles, focussing on waste and carbon generation in the Welsh economy as a case study. However, we take a different focus, arguing that the 'domestic technology assumption', taken as something of a mid-point in moving between production and consumption accounting in the first paper, may actually constitute a more useful focus for regional policymakers than full footprint analyses.

PAP, CAP and environmental accounting methods within an input-output framework

As explained in the previous paper, the issues involved in developing carbon accounting methods have been the subject of a two year ESRC Climate Change Leadership Fellowship (CCLF) programme led by Dr Karen Turner at the University of Stirling (previously at the University of Strathclyde) and involving collaboration with the co-authors of this paper. The work of the CCLF has involved examining different perspectives on pollution accounting methods using input-output tables as a means of examining the structure of pollution problems. Input-output tables are commonly constructed as part of national government accounting and provide a view of economic activity, in particular the sales and purchase relationships between industries, government and households. Such input-output tables are produced regularly in Wales by the Welsh Economy Research Unit. When combined with data on the carbon produced by different industries, and by households, these tables provide a means through which one can examine how different demands create environmental consequences up the supply chain.

In short, the production of goods and services generates pollution, but this pollution is ultimately only generated to meet final consumption demands. An environmentally extended input-output system takes data on the emissions generated in production and attributes them according to the underlying pattern of final consumption. By attributing pollution to different types of final consumption demands (such as households, local government, capital formation and export demand) we can better understand which actors in the economy are driving the pollution. The following example may help to illustrate the underlying issue.

As part of the CCLF programme, a series of knowledge exchange events have been held. One anecdote from an ESRC Festival of Social Science event highlights the issues under consideration here. The event at the University of Strathclyde involved pupils from high schools in Glasgow. At the beginning of the session the following question was posed: who is responsible for emissions generated as a result of a pupil drinking a glass of Spanish orange juice at breakfast? Is it the pupil, or those who made the orange juice in Spain? The immediate answer was that it was the pupil's (the consumer's) responsibility. This answer was very much in line with the consumption accounting principle

approach discussed above. At the end of the session, and having taken the pupils through a discussion of international climate change negotiations and the various aspects of international pollution abatement, the response to this question was not as overwhelmingly one-sided as pupils took more of a 'shared responsibility' view.

This anecdote helps to demonstrate why it is necessary to consider a range of different perspectives to fully understand pollution accounting issues. It perhaps also explains why there is a lack of agreement at international and national levels on how we should attribute emissions across jurisdictional boundaries. However, while there is a lack of institutional agreement, there has been increasing public interest in consumers taking responsibility for the emissions embodied in their behaviour. In turn, this has led to increased interest in CAP based footprint measures, arguably the most popular of which is the carbon footprint (Wiedmann, 2009).

Carbon footprint analyses have recently been carried out for a range of different organisations, activities, and countries. Notable non-state level examples include carbon footprint estimates for Irish households (Kenny & Gray, 2009), and for the Scottish Parliament (Weidmann et al, 2008). National level carbon footprint estimates are reported in Pan et al (2008) for China, Peters and Hertwich (2006) for Norway, Druckman & Jackson, (2009) for the UK, Maenpaa & Siikavirta (2007) for Finland, and many others. Almost all of these studies utilise input-output data to generate their carbon footprint estimates.

A full carbon footprint measure requires detailed information about the pollution embodied in trade. Due to globalisation, an accurate estimate of such a measure, in almost all cases, would require a vast and complex database detailing the pollution embodied in hundreds of different trade flows. Such a database would be akin to a world input-output system. Given these often prohibitive data requirements, simpler measures are frequently adopted to estimate carbon footprints. In using these simpler measures, there is a loss of 'purity' in the analysis, but there are huge gains in tractability and computability. Moreover, a focus on full footprint measures could be misleading to policymakers as it suggests that there is little value in other consumption-driven measures. Our goal here is to demonstrate that it is only through considering other consumption driven measures that particular policy questions can be answered.

The principle policy tools that governments can use to reduce domestic pollution generation tend to focus on domestic (both producer and consumer) behaviour. Some examples of policies used on the production side include subsidies for pollution abatement activities undertaken by companies, investment in renewable energies, and tougher pollution regulations for industry. Governments are more limited when it comes to policies intended to reduce the emissions embodied in imported goods, especially a regional government such as Scotland or Wales. For example, the Welsh Assembly Government has little ability to alter foreign production. However they can work to change aspects of domestic consumption behaviour. Then practically reducing the emissions embodied in imports is not as straightforward as amending domestic pollution regulations.

So how might we go forward to provide transparent information for policymaking purposes while avoiding the practical issues of developing an expensive and vast database of pollution embodied in domestic imports? One potential way ahead is to adopt what is known as a domestic technology assumption (DTA) method. This method retains the local production processes as a key determinant of the carbon footprint estimate, but focuses on local final consumption decisions as the main driving force. In this way, we propose that, as well as offering a solution in the absence of data on polluting technology used in producing goods that we import, it is also useful in considering the jurisdictional issues involved in pollution abatement.

For example, without data on production and pollution technologies of all trading partners, it may be useful for regional (e.g. Welsh) policymakers to examine the global environmental impacts of domestic consumption behaviour as if it were being satisfied using the local production technologies, which they can directly affect. In short, this approach assumes that Welsh imports, regardless of the country of origin, are produced using similar technologies to those used in Wales and that their production has similar carbon consequences. Alternatively, one may view the approach as allowing us to consider the domestic savings of not producing goods and services locally, rather than the implied costs abroad. In what follows we illustrate a footprint approach using a domestic technology assumption from work we have undertaken in Wales (Jensen et al 2009, 2010).

Case studies of waste and carbon generation in the Welsh regional economy

The Welsh Assembly Government has a legal duty to pursue sustainable development objectives as part of its core functions. Moreover, a series of strategic planning documents highlight the importance of the long-term reduction in externalities such as carbon emissions and waste. There has been growing interest from Welsh policymakers in measures that estimate the global footprint associated with Welsh production and consumption activity. In this context, much of their focus has been on the ecological footprint measure which links regional consumption to global land areas needed to support that consumption. Using this measure, Wales has been found to be consuming more than its fair share of the Earth's resources. In this paper, we focus on the carbon and waste footprints of Welsh consumption that have been estimated using an environmentally extended Welsh input-output framework.

To illustrate the approach outlined in the previous section we have used the Welsh input-output tables for 2003 (WERU, 2007). These tables (which adopt the same format as outlined in the schematic detailed in the first paper in this special issue) provide information on the total use of imported and regionally produced goods and services by each Welsh production sector and by different types of final consumers (e.g. households, tourists, government). The input-output data were then extended with data on physical waste and CO2 (as carbon) directly generated by each sector of the economy (including households). This extension allows us to examine the total waste and carbon that is directly generated by each production sector and final consumption activity within the Welsh economy.

Using these data and applying the DTA approach discussed above, we assume that the waste and pollution intensities of production are given by Welsh technology, irrespective of the actual location of production. As a result we can then explore the level of pollution directly and indirectly (i.e. through industry supply chains) embodied in different types of production and consumption activities. However, in the case of carbon we aim to relax this assumption using data on the sources of imports and the corresponding direct carbon intensities that apply in the producing region, as has been done for Scotland and the UK in the first paper in this issue.

The input-output data for 2003 show that Wales ran a combined trade deficit with the rest of the UK (RUK) and the rest of the world (ROW) of almost £8.5bn (just under £3bn with other UK regions and just over £5.5bn with the rest of the world). That is, imports of goods and services exceeded exports. The fact that Wales did not produce enough to meet its own consumption requirements suggests that its environmental footprints are expected to reflect significant external impacts in other regions and countries.

Table 1: Input- Output accounting of the Welsh waste trade balance (2003)

	PAP	CAP
Total Waste Attributed (millions of tonnes)	18.61	29.77
Waste supported by Welsh household and government final consumption		
Domestic (Welsh) waste generation:	1.52	1.52
Directly generated (households)	7.02	7.02
Indirect- generated in Welsh production sectors	8.54	8.54
Indirect waste embodied in imports (DTA)		21.22
Waste supported by external demands for Welsh production	10.07	
Implied Waste Trade Balance (Deficit):		
Actual waste generation minus DTA waste generation		
(Waste embodied in exports minus waste embodied in imports)	-11.15	

Taking the case of physical waste generation first, Table 1 reports the results for two different types of accounting. In the first column, titled PAP (production accounting principle), we examine the total physical amount of waste generated within the Welsh borders (i.e. 18.6m tonnes). Welsh waste generation under PAP is calculated by multiplying the individual sector output and final consumption expenditure data given in the input-output tables by Welsh-specific direct waste intensities (tonnes of waste per £1m output/final consumption expenditure). We also use standard techniques to attribute this domestic waste generation to the final consumer groups identified in the input-output tables. These are domestic final consumption (i.e. households and government) and external final consumption (exports). These results allow us to distinguish between waste generated in Wales as a direct or indirect by-product of domestic final consumption demand (8.5m tonnes) and external (export) demand (10m tonnes). Thus, we can conclude that the bulk of waste generated within Welsh borders takes place to support external rather than domestic final consumption demand. However, the PAP measure in the first column does not tell us anything about the other element of trade in waste: the amount embodied in imports.

The advantage of the CAP results in the second column of Table 1 is that, as discussed above, it does account for the fuller waste implications of Welsh final consumption. Under the CAP approach, waste generated within Welsh borders as well as waste generated in other regions and countries to support Welsh final consumption demand is accounted for. Here, using the DTA, we address the waste generated outside of Wales by using information in the Welsh input-output table framework (including data on the domestic and imported inputs to production), information on combined final demand (including imports supported by household and

government spending for example) but assuming Welsh direct waste intensities.

Under the CAP measure, the 10.1m tonnes of waste generated in Wales to support external demands (included under the Welsh PAP account) are excluded from the Welsh waste footprint In formulating our DTA-based CAP measure, we therefore exclude the waste generated in Wales to meet export demand and include a measure of the waste embodied in Welsh imports (i.e. imports that directly and/or indirectly service the final demands of Welsh households and government).

In the second column of Table 1, we instead account for the (indirect) waste generation in other regions and countries, estimated using our domestic technology assumption approach, to be embodied in imports to Welsh final consumption. Domestic waste generation to meet Welsh domestic final consumption demands remains the same as under the PAP measure in column one (this element is common to both PAP and CAP; the difference lies in the treatment of waste embodied in trade). Our CAP measure shows that in 2003, Wales had a waste footprint estimate that greatly exceeds the waste accounted for under PAP. Our results show that if we assume Welsh production and waste technologies are adopted by Welsh trading partners, there are 21.2m tonnes of waste embodied in imported consumption demands. As only 10.1m tonnes of waste are attributed to external (export) demands in the PAP method, this implies that, as well as running a trade deficit in terms of goods and services (with the value of imports exceeding that of exports), Wales runs a waste trade deficit with the rest of the world (including the rest of the UK). This reflects the fact that the waste embodied in Welsh exports is less than the waste estimated to be embodied in imports.

Table 2: Input- Output accounting of the Welsh carbon trade balance (2003)

	PAP	CAP
Total CO2 as carbon attributed (millions of tonnes)	11.75	10.86
CO2 supported by Welsh household and government final consumption		
Domestic (Welsh) CO2 generation:	2.13	2.13
Directly generated (households)	1.91	1.91
Indirect- generated in Welsh production sectors	4.04	4.04
Indirect CO2 embodied in imports (DTA)		6.83
CO2 supported by external demands for Welsh production	7.71	
Implied CO2 Trade Balance (Deficit):		
Actual CO2 generation minus DTA CO2 generation (CO2 embodied in exports minus CO2 embodied in imports)	0.88	

However, it is not necessarily true that when a country runs a trade deficit in goods and services, it will also do so in environmental terms. One benefit of using an input-output approach to account for environmental issues is the level of detail on the composition of regional consumption and trade patterns behind these calculations.

The calculations underlying the results presented in Table 2 use the same methodology and economic data as those in Table 1. The only difference is that data on the direct CO2 (as carbon) intensity of Welsh production and consumption activities are used instead of physical waste intensities. The key result in the case of carbon is that the Welsh carbon footprint (under CAP in column two) is less than actual carbon generation within the Welsh economy (estimated under PAP in column one). Once again the carbon generated in Wales and attributable to domestic final consumption demands is the same under both measures (4m tonnes). However, carbon generation within Wales to support external (export) demand (7.7m tonnes) is greater than the carbon that we estimate to be embodied in imports to Welsh final and intermediate consumption demand (6.8m tonnes). This suggests that Welsh exports contain more carbon than its imports, i.e. Wales had a carbon trade ‘surplus’ of just under 0.9m tonnes in 2003.

The qualitative differences in our analyses for waste and carbon are interesting, and largely due to the composition of imports. For example, although accounting for only a small share of the value of total imports, the bulk of waste embodied in Welsh imports is related to imports from ‘Construction’ and ‘Other Mining and Quarrying’ activities (although these only account for a small share of total imports; note also the bulk of this waste is likely to be inert, not hazardous, waste). Simple differences such as these result in the estimation of a much greater waste, as opposed to carbon, impact for imports from these sectors. This result also suggests that examining the differences between our results for carbon and for waste at the sectoral level may be useful for policymakers interested in determining which

industries to focus on in order to reduce different types of pollution.

Discussion and conclusions

The analyses reported in Tables 1 and 2 both employ the DTA method to calculate the waste and CO2 (as carbon) embodied in imports by assuming that the waste/carbon embodied in the production of the commodities consumed is given by Welsh production and polluting technology. This allows us to consider the Welsh waste and carbon footprint as if all consumption and production technology decisions were made under the jurisdiction of Welsh policymakers. As explained above, we believe that there is valuable information for both the public and for policymakers in this approach. This is because it facilitates the consideration of the environmental footprint of our consumption decisions under circumstances over which we have control (i.e. 'as if' a region had to meet all consumption demands based on that region's own consumption and technology decisions).

The DTA approach only provides hypothetical footprint estimates, but has the advantage of being implementable using domestic input-output data. We could relax the DTA where appropriate data on the carbon, waste (or other pollutant) content of imports is available. In our current research, as reflected in the Scottish and UK results reported in the first paper in this issue of the Fraser Commentary, we are collaborating with colleagues at the OECD to produce a dataset that will allow us to look at these issues in more detail.

However, as we have already argued in this paper, getting a more accurate footprint measure is not the same as fully understanding the impacts of our actions. As a general principle, we question how much is gained by adopting an approach using more international trade and waste data. That is, while it allows for a more accurate footprint measure, what is the value-added in policy terms (given that these international data provide information on technologies adopted in other regions/countries? A full footprint measure may be more 'accurate' but as a practical tool for policymakers, it may be nothing more than a performance indicator. On the other hand, different perspectives, such as the DTA method, allow policymakers to examine the impact of production and consumption behaviours that local policymakers have control over.

While this paper reports on our analyses of carbon and waste, this approach is easily generalised for the analysis of other environmental externalities. We believe that there is a growing demand among policymakers and the public to better understand the global environmental consequences associated with their consumption choices. The challenge for the research community is to develop measurement approaches that are transparent and provide useful information on which policy choices can be made and progress towards sustainable development objectives can be assessed. Following from the CCLF research discussed in this paper, the research team is actively liaising with the policy community to explore ways in which the tools described can be extended and improved. In our continued research we are also working on developing more complex modelling applications through which one can explore the consequences of changes in policy on industry and consumer behaviour (for example, through the use of computable general equilibrium, CGE, modelling frameworks).

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Endnotes:

[1] The interested reader is referred to Munksgaard & Pedersen (2001) which was one of the first papers to explicitly address consumption v. production accounting principle approaches in the literature.

Scottish climate change policy: an overview*

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1. Introduction

Despite much of energy policy being a reserved issue for the UK Government, Scotland has pursued its own distinctive energy policy (Allan et al, 2008a), particularly in relation to climate change. The Climate Change Act (Scotland) was passed in 2009 and outlines Scotland's commitment to tackling climate change. It requires Scottish greenhouse gas (GHG) emissions in 2050 to be 80% less than their 1990 levels, with an interim target of a 42% reduction by 2020.

Climate change is an international problem which appears to require a global solution and it is therefore not clear that the appropriate spatial scale for policy action is the regional or even national level. The Scottish Government is aware of this, but claims that such emissions' reduction targets can be used as a means of supporting the UK's international commitments and also showing leadership to encourage other nations to tackle climate change. However, Scottish climate change policy must also be considered in the context of Scottish energy policy as a whole. The Scottish Government has other energy policy goals, notably security of supply, affordability and economic growth through the development of low carbon technologies, notably renewables.

This paper is intended to provide a brief overview of the main issues involved in Scottish climate change policy. We give a brief background, in Section 2, on international, EU and UK climate change policy. In Section 3 we provide an overview of the main features of the Scottish Climate Change Act and highlight particular differences with the UK equivalent framework. In Section 4 we discuss the issues surrounding low carbon technologies and their impact on climate change policy in Scotland. We consider the policy instruments available to the Scottish Government while functioning within EU and UK frameworks in Section 5. In Section 6 we conclude and identify avenues for future research.

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2. Background on International, EU and UK policy

Given the global nature of the climate change issue, most initial policy effort has been on international or multi-national levels, like the EU. There has also been considerable effort at the UK level. Scottish climate change policy is heavily influenced by and conditional upon policies at these other spatial levels. This section therefore gives a short summary of the main agreements, policies, instruments and legislation that affect Scotland.

The Kyoto Protocol to the United Nations Framework Convention on Climate Change (UNFCCC) is an international agreement that imposes reduction targets on GHG emissions for developed nations. It was established in 1997, ratified in 2005 and runs from 2008-2012. No legally binding successor agreement has yet been agreed, although the informal Copenhagen Accord was adopted in 2009 as a step towards this. Kyoto allows countries to use various, specifically created, flexible market mechanisms in meeting their emissions reduction commitments. These are International Emissions Trading, Joint Implementation (JI), and the Clean Development Mechanism (CDM)[1]. In theory all these mechanisms should allow emissions abatement to take place in the most cost effective manner i.e. where it is cheapest, and also allow for the diffusion of low-carbon technologies to developing countries.

Under the Kyoto Protocol, the EU-15 countries have a bubble which allows them to achieve together an overall target of an 8% reduction in emissions by 2012. In order to achieve this reduction the EU created its own instrument in the form of an emissions trading scheme, the EU ETS, in 2005. The EU ETS is a 'cap and trade' system where a limit is put on total emissions based on Kyoto commitments and the scheme allows CO2 allowances, called European Union Allowances (EUAs), to be bought and sold between operators in certain emitting sectors[2]. The sectors currently covered are: energy, ferrous metals, minerals, pulp and paper. Each EUA is equivalent to one tonne of CO2. All installations within these sectors require a permit to operate which covers almost half of EU carbon emissions. However the allocation of the tradable EUAs to permit holders is initiated at national level with individual Member States submitting National Allocation Plans (NAPs) to the EU Commission for approval on the distribution of allowances and details of all installations covered. Phase I of the EU ETS ran from 2005-2007 and Phase II runs in parallel with Kyoto from 2008-2012.

In 2008 the EU introduced its 20-20-20 targets for 2020. This EU goal requires that by the year 2020 there will be a 20% reduction in GHG emissions, to have 20% of final energy consumption met from renewables and a 20% reduction in energy consumption through promoting energy efficiency. The EU stated that it would increase its emissions reduction commitment from 20% to 30% if an international successor to Kyoto was agreed and other

countries adopted strict targets. Although there is an EU renewables target, there is no EU-wide renewables[3] policy instrument and each member state have their own renewables target and can meet it by whatever method they deem appropriate.

The Climate Change Act 2008 outlines the UK's contribution to tackling climate change by setting UK emissions targets for 2020 and 2050. The Climate Change Act also created the Committee on Climate Change, an independent body tasked with advising the UK Government on setting its emissions targets, including 5-year carbon budgets, and monitoring government progress towards the targets. The UK emissions reduction target for 2050 of 80% is the same as that for Scotland[4] but the 2020 target is dependent upon a global climate change agreement being struck. If such an international deal is agreed, then the EU will raise its own emissions reduction targets (from 20% to 30%) and thus the EU Emissions Trading Scheme (EU ETS) cap will be tightened. This will require greater reductions from UK installations covered by the EU ETS i.e. the traded sector, which includes electricity generation. Therefore the UK Government has set a 2020 "interim target" of a 34% reduction but this will rise to 42% "intended target" if international and EU policies dictate so[5]. The overall UK target in 2020 is therefore conditional upon the EU target which is in turn dependent upon a global deal. This framework shows that the UK is willing to demonstrate leadership with its initial effort but that it will also commit to higher targets if others are willing to make more significant reductions.

"This leadership argument is best understood in game theory terms: it is an attempt to induce steps towards a global carbon cartel to reduce the quantity of emissions."[6]

It is also worth stating that the UK has adopted a renewable energy target of 15% by 2020 as its contribution towards the wider EU renewables target.

3. Scottish Climate Change Act

Strict targets

The Climate Change (Scotland) Act sets a 2020 target which is more ambitious than the UK equivalent. Scotland has legislated for a 42% reduction in emissions regardless of what occurs at any other spatial level[7]. Such ambition may be laudable in principle but it must be informed by, and be consistent with, EU and UK policy and account for the likely impact of these other spatial levels. This therefore raises the question of whether it is possible for Scotland to meet the 42% target, especially if there is no global deal. The advice from the Committee on Climate Change (CCC) is that achieving the 42% target is possible but the CCC recommends setting separate targets for the 'traded' and 'non-traded' sectors in Scotland. The traded sector emissions will be counted as Scotland's share of the UK allocation in the EU ETS (CCC, 2010). This is in the spirit of the EU ETS, where the geographic distribution of emission reductions simply reflects the least-cost locations for meeting the overall cap. However, it also implies that, from a purely Scottish perspective, any extra reduction in traded sector emissions, for example, associated with the expansion of renewable electricity generation, will not count towards meeting the reduction targets[8]. This accounting methodology also implies that any non-CO2 GHGs produced within the traded sector, such as methane, will not be counted as Scottish emissions[9].

As for the non-traded sector, the CCC predicts that, with no global deal, there would have to be a 47% reduction in non-traded sector emissions to meet the overall Scottish target of 42%.With a global deal the non-traded sector target falls to 39%[10]. It seems perverse that the non-traded target shrinks if a global deal is agreed. The CCC therefore suggests making Scotland's non-traded target invariant to the achievement of a global deal. This seems logical because if Scotland wishes to make its framework invariant to international agreements, then at least one target, the non-traded sector, must be made invariant to reduce uncertainty. Given that Scotland is part of the EU ETS, there is nothing that can be done to make the overall target invariant.

Annual targets

The Climate Change (Scotland) Act has established the requirement of yearly carbon budgets in Scotland. It will be interesting to see how these are set and met in comparison to the UK budgets, which are set for 5-year periods.
The frequency with which budgets are set reflects a trade-off between certainty in the future emissions path and flexibility in meeting targets. Annual year-on-year targets provide certainty for investors, provided that there is confidence that these targets will be met. However, setting 5-year budgets allows for the benefits of flexibility in response to uncontrollable events and a lower reporting burden.

Of course annual targets do not necessarily imply certainty; increased frequency may make it more difficult consistently to achieve targets. For example, if a nuclear station had to shut one year unexpectedly then other types of electricity generation, most likely coal and gas, would need to make up the difference and thus emissions would substantially increase for that single year. This issue is especially important given Scotland's current dependence on a small number of large generators[11]. Less frequent budgets would allow Scotland to cope better with these unexpected fluctuations. The CCC's report to the Scottish government (CCC, 2010) has expressed concern with the lack of flexibility in the Scottish annual targets and suggests measures could be considered to increase flexibility, although it is not within the CCC's remit actually to recommend doing so.

An issue with setting 5-year budgets is defining exactly how the budgets are expressed because the stock of carbon in the atmosphere is more important for global warming than

the flow. For example, meeting the 5 year target by a large reduction in the final year will leave more carbon in the atmosphere, and cause more global warming, than a gradual reduction.

Targets for 2011 and 2012 are relatively small reductions, most likely due to the recession but from 2014 onwards there is a 2-3% decrease in emissions year on year. There is a substantial one-off increase in emissions reductions in 2013 (9.9% relative to the previous year) due to the beginning of the third phase of the EU ETS and therefore the expected tightening of Scotland's allocation in the traded sector. The Act requires reductions from 2020 to be at least 3% each year.

The Scottish annual targets were initially to be passed in secondary legislation in April 2010 but the first set of targets were rejected by a slight majority in the Scottish Parliament for not going far enough, as a pledge of annual 3% reductions each year was made in the SNP manifesto. A short-lived cross-party working group was then established to revisit these annual targets and suggest amendments. The targets shown above have been set out in the most recent Draft Order (not yet legally binding) laid before Parliament in September 2010.

Aviation and shipping

International aviation and shipping both cause considerable GHG emissions and so the Scottish framework explicitly includes international aviation and shipping in its emissions reduction targets. However, these are not yet included at the UK or EU level and there is no agreed method for accounting for these sector's emissions. The main question to ask is whether the Scottish Government can influence emissions in these sectors. If it cannot, then what are the implications of including them amongst the target reductions; and even if the Scottish Government can influence those emissions, would it be desirable to do so unilaterally?

There is likely to be considerable growth of emissions in international aviation and shipping, given previous trends. Therefore action on these sectors is imperative for tackling climate change. However, the ability to make significant reductions in these sectors is mostly outwith Scottish Government control unless it plans to severely limit travel and exports[11.] Due to the international nature, the CCC do not attempt to identify policies that the Scottish Government could use to reduce emissions in these sectors. Instead, given the growth trends in international aviation and shipping, the CCC (2010) believes that GHG emission reductions of 44% will be necessary in the other sectors of the economy (i.e. the total economy less aviation and shipping) in order to meet the 42% Scottish target.

Even if it were possible for the Scottish Government to reduce its emissions from aviation and shipping, it seems inappropriate, given the international nature of these sectors, to include them in national targets before they are included on an international scale. Limiting emissions in these sectors before other countries could lead to serious competitiveness affects. Exactly how these sectors are included is also an issue because the production-orientated-nature of the targets makes it difficult to attribute emissions accurately. These sectors would lend themselves better to a consumption-based accounting methodology. It seems more likely that separate international sectoral agreements will be required in the long-run.

From 2012 domestic aviation will be part of the EU ETS traded sector and will therefore be outwith Scottish control for accounting purposes. A specific issue with the EU ETS is that it only targets CO2 and therefore misses many of the other greenhouse gases (GHGs) attributable to aviation which are included in the emissions reduction targets.

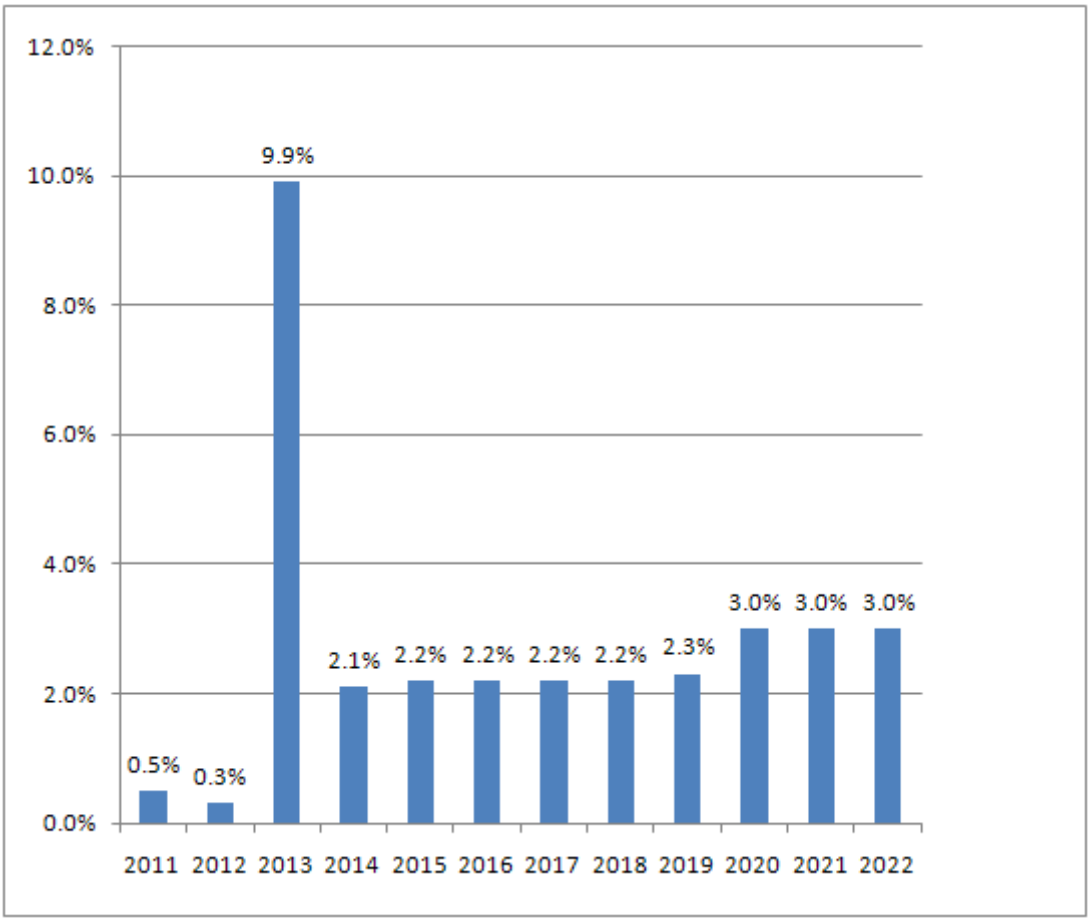
Banking and borrowing

There is no banking or borrowing allowed between each year of the annual Scottish emissions budgets. Each yearly budget must be met, and any over-fulfilment cannot be carried over into future periods. This provides certainty in terms of targets but severely reduces the flexibility of meeting them, especially in years of significant variation in energy use and there is also no incentive to go beyond the necessary in reducing emissions in a given year. If targets are consistently met this may be very beneficial as the credible policy provides certainty to investors. However, if targets are frequently missed, in part because of their inflexibility, then the credibility of the annual targets will ultimately be undermined and perhaps the credibility of the government as a whole. If there are signs of this happening in practice then banking and borrowing should be considered as a means of allowing budgets to be met more flexibly between years. For example, annual targets cannot take into consideration outside events such as colder than anticipated winters, power generation shutting down or a *force majeure*, such as the limited air travel due to the volcanic ash in April 2010.

Use of credits

Purchase of credits may be used to help Scotland achieve its emissions reduction targets. These may be through the EU ETS or the various Kyoto mechanisms which are discussed in Section 2. As discussed already, there is no limit on the use of European Union Allowances (EUAs), as these can be freely traded within the EU ETS and will count towards Scotland's traded sector target. However, there is a limit on the "offset credits" purchased from the Kyoto flexible mechanisms such as JI or CDM. The Climate Change Scotland Act puts a limit of 20% on emissions reductions

Figure 1: Scottish annual climate change targets - % decrease from previous year



Source: http://www.scotland.gov.uk/News/Releases/2010/09/22133935

being made by purchased Kyoto credits which can be used to meet the non-traded sector target. This cap is set to ensure that the emissions reductions are met mainly through domestic measures. Theoretically these flexible mechanism projects would achieve abatement at lowest cost. However, there are two concerns about their use. Firstly, extensive use of credits would not incentivise the necessary changes in the infrastructure of the economy to put the country on a path to making its 2050 reduction. This would leave us dependent upon reductions in other nations to make the target. Secondly, there are concerns that no significant reductions would be made if the use of Kyoto credits are not limited, as uncertainty exists about their true benefits. This scepticism is due to the difficulty in proving the 'additionality' of such projects against a hypothetical baseline scenario. If these projects are really not credible, then the whole process could be undermined[13]. Therefore domestic emissions reductions, which can be more accurately measured, are the preferred means of meeting the targets.

Given the lack of flexibility of annual targets and the absence of banking or borrowing, then purchasing credits may become important as a method of meeting Scottish targets in years of fluctuation in emissions. This may be expensive. The CCC (2010) suggests credits may have to play a significant part in Scotland meeting its emissions reduction target, especially if there is no global deal. They estimate that a 20% emissions reduction commitment by the EU would require Scotland to purchase credits from the Kyoto mechanisms to cover a range of 9% to 17% of its reductions at an estimated cost of around £30million to £50million in 2020 in order to meet its emissions reduction targets. This is the most likely scenario but would fall within the 20% limit on credits set in the Climate Change Scotland Act and so would allow Scotland to meet its emissions reduction target. The amount of credits needed to contribute would be much less under the stricter 30% EU target, with up to 5% of the 2020 target being met by offset credits costing a maximum of £15 million (CCC, 2010, p. 42). Only time will tell if circumstances arise in which the Scottish Government must buy credits to meet their own self-imposed targets and if so, how they can justify this spending to the public

4. Low carbon technologies

As stated in Section 3, under the accounting principles of the Climate Change (Scotland) Act, low carbon technologies

cannot contribute towards meeting emissions reduction targets at Scottish level. This is because the UK's emissions targets are bound to the EU ETS. Low carbon technologies cannot affect Scotland's performance in meeting its emission reduction targets because emissions from electricity production are covered by the EU ETS. In theory a policy instrument such as the EU ETS, which prices carbon, should achieve the necessary emissions reductions efficiently and thereby induce the desired level of investment in low carbon technolgies. Therefore having a renewables target (and corresponding instrument, such as ROCs, discussed below), for example, only serve to raise costs and so prove inefficient. However, Sorrell and Sijm (2003) argue that, although additional policy instruments bring no efficiency gains, they can achieve other objectives such as stimulating investment in R&D where inducing initial investment is difficult because of moral hazard and imperfect information. In a Scottish context, renewables can be seen as contributing to other Government energy policy goals such as security of supply, and offering potential for economic development through the exploitation of low-carbon technologies.

Independently of the emissions reduction targets set out in the Climate Change Scotland Act, the Scottish Government has other policies and targets for the traded sector, in particular energy generation. The details and possible motivations of these policies are discussed below.

A 'no new nuclear' policy is held by the current Scottish Government with regards to Scotland's energy portfolio[14]. This is especially important given that Scotland's nuclear generating facilities are coming to the end of their life with Hunterston and Torness both scheduled to close (some 30% of Scotland's electricity is currently generated by this source). Furthermore, a substantial proportion of coal-fired power plants are due to retire by 2016. The "no new nuclear" position is not enshrined in any legislation but reflects the stance of the two main political parties. This may partially reflect concerns of safety and disposal and also a perceived link between nuclear energy and nuclear weapons. In terms of climate change policy, a lack of nuclear capacity limits the options available for low-cost, low-carbon technologies available to replace emissions-intensive electricity generation. The UK government is pursuing nuclear within its future energy portfolio, and given the integration of the British electricity market, it will be the case that the costs of the UK government developing nuclear power will be distributed among all British electricity consumers, including those in Scotland (Bellingham, 2008).

It is not clear how Scotland will fill the energy supply gap but most likely this will be through the harnessing of various renewable energy sources[15]. In practice the energy gap will be met by market circumstances and investor decisions, however, the Scottish Government can indirectly attempt to influence the energy supply through its renewables policy. This is reflected in the fact that the Scottish Government has recently set a very demanding renewable electricity target of 80% for 2020 i.e. 80% of Scotland's electricity consumption must come from renewable sources[16]. The Scottish Government sees the potential benefit that renewables can have in terms of achieving energy policy goals, such as stimulating economic growth and promoting security of supply through diversity of generation sources. However, if the Scottish Government believes that renewables are contributing towards achieving Scottish climate change targets, they are misguided. Also, it is highly unlikely that strict climate change targets will do much in practice to help attract substantial investment in low-carbon technologies. Regardless of these facts, the CCC believes there is still a need for low carbon generation, even if it is not part of the emissions targets, because "given that Scotland has an 80% target to reduce emissions, it is important not only that the traded sector cap is achieved, but that the way this is achieved is consistent with the longer-term path to an 80% emissions reduction in 2050 relative to 1990. Specifically, this path requires early decarbonisation of the power sector, and extension of low-carbon power to other sectors, namely through electric forms of transport and heat[17]." This reasoning appears to be based upon long-term R&D considerations. Towards 2050 there will be increased electricity requirements, for instance, through significant predicted increases in electric transport. During the next few decades, as we have already stated, there will also be retirement of many current power generators. It therefore makes no sense to provide this electricity from dirty generating sources if we are serious about reducing emissions. However, there is not a credible carbon price that extends this far into the future. Therefore there is a need to put significant research and development into renewables in order to provide a diverse, low-carbon power sector.

Meeting the 80% renewables target, while providing an adequate energy supply, will require tapping into the extensive renewable energy resources available in Scotland. A significant anticipated benefit is job creation in renewables and other "green" industries. This may also lead to Scotland becoming an exporter of renewable energy (Allan et al, 2007) and possibly also an exporter of renewable technology itself and its operative and management experience (Allan et al, 2010b). These benefits will only be fully realised if renewables projects embody limited imported materials and labour[18]. Onshore wind has been the major technology deployed so far in Scotland but it brings its own problem because of its intermittent nature, and therefore variable output, requiring a back-up to ensure supply meets demand[19]. Offshore wind and marine technologies have the potential to play an important role in Scotland given their abundance, although the peripheral location of the most promising resources provides new challenges to distribution and transmission[20]. It is estimated that Scotland has 25% of Europe's Tidal and Offshore wind power and 10% of its Wave power potential.

Carbon capture and storage (CCS) technology also has the potential in Scotland to stop emissions from coal or gas

combustion being released into the atmosphere. CCS could be fitted to new or old power stations and allow for the use of coal and gas but without their significant CO2 emissions reaching the atmosphere. This is likely to be expensive to fund however as the technology has not yet been tested on a commercial scale, and these costs will likely be passed onto consumers through higher energy prices. The UK government announced a CCS demonstration competition as well as setting up an Office of Carbon Capture and Storage to coordinate the approach to CCS in the UK; this appears to be somewhat behind schedule. The EU has also passed a Directive on CCS and will use EU ETS proceeds to fund up to 12 CCS demonstrations. The development of CCS may take some time but Scotland has substantial capabilities to use its experience with the North Sea oil and gas industry, and the availability of extensive underground storage capacity, to help become a leader in CCS technology and use it to help achieve its environmental goals. The Scottish Government has produced its own roadmap as to how Scotland can become Europe's leader in CCS technology (Scottish Government and Scottish Enterprise, 2010), the funding of which will be through EU and additional Scottish Government support. The export potential of CCS is particularly significant given that it could be adopted worldwide in countries which use coal and gas. In terms of the EU ETS it is not clear what will happen with CCS. Perhaps those installations fitted with CCS will be exempt from the EU ETS or they will otherwise be able to sell all their allowances. Overall, renewables should be preferred over CCS because although CCS helps to decarbonise the economy, in the long run and we would still be reliant upon finite fossil fuels and so it does not help address the energy supply. However, this does not diminish the value of CCS as an incredibly useful but ultimately short-to–medium term solution to reduce carbon emissions across the globe.

5. Policy instruments

Scotland is part of the United Kingdom and the European Union, and as such is subject to many of their climate change policies. At EU level Scotland is already included in the EU 20-20-20 targets for 2020 and policy instruments such as the EU ETS. At the UK level there are instruments such as the Climate Change Levy and the Carbon Reduction Commitment, renewables instruments such as Feed-in Tariffs (FiTs) and ROCs and there are institutions such as the Carbon Trust and the Energy Saving Trust. The Scottish Government must adhere to these given their limited devolved powers but must also use what it has at its disposal to achieve its own goals and the annual targets it sets.

The setting of emissions targets themselves may be seen as an instrument with which to achieve Scottish climate change goals. If targets are believed to be credible (i.e. in practice, if they are met year on year) then the mere setting of them may influence expectations sufficiently to alter behaviour, for example to induce investment in low carbon technologies. However, any such impact is likely to be short-lived if the Scottish Government consistently failed to meet its targets. It seems unlikely, in practice, that targets could be judged as being instruments, especially as there is no clear policy lever to make sure they are met. However, additional credibility of the targets may be brought about by advice on, and monitoring of, targets by an independent agency. The Climate Change (Scotland) Act allows for the possibility of a Scottish Committee on Climate Change to provide advice and progress towards annual targets. So far this possibility has not been utilised. However the Scottish Government commissioned a report from the Committee on Climate Change whose role it is to do this for the UK government (CCC, 2010)[21].

The Scottish government has some other available options in terms of policy instruments. Firstly, the Scottish Government has been able to use its planning powers to help accelerate the achievement of its goals. An example of the use of planning permission is the acceptance of the Beauly to Denny power line, the creation of which will substantially enhance grid capabilities in Scotland. It will allow for easier transmission of electricity, in particular that generated by renewable sources located in peripheral areas to places of high energy consumption. Secondly, the Scottish Government can make funding available for energy efficiency improvements and legislate to ensure efficiency standards in important emitting sectors such as transport, housing and agriculture. This may be through regulating efficiency standards e.g. of insulation, heating and lighting and also undertaking demand-side initiatives for transport, such as encouraging public transport, car sharing and lower speed limits. Thirdly, there is the option of purchasing offset credits from the Kyoto mechanisms in order to meet emissions reduction targets. This may prove to be the cheapest option in the short-run if the price of these credits are low but, given the limit of 20% credit purchase in the Climate Change (Scotland) Act, they cannot rely heavily upon credits. A fourth possible, but ultimately unlikely, action is for the Scottish Government to use its limited fiscal powers to inhibit growth in the economy in order to satisfy their climate change targets. This is highly unlikely given the potential consequences of such action but it should be noted that sustained low growth may make the achievement of targets possible i.e. targets may be met entirely fortuitously, rather than as a consequence of policy action.

In practice, the uptake of renewables will be achieved, not by climate change or renewables targets, but by direct funding and financial support over the time-scale necessary for investments. Extensive exploitation of renewable sources will require substantial funding by the Scottish and UK Governments in conjunction with the regulator Ofgem, given the integrated nature of the electricity market. How renewables are funded is a political decision but one which requires a balance between potentially "picking winners" on the one hand and effectively encouraging only the technology closest to market (a consequence of a "technology blind" approach). In the UK, renewables are substantially supported by the Renewable Obligation

scheme which the Scottish government helps coordinate with other administrations and which Ofgem administers. This is a trading scheme that requires electricity suppliers to provide a certain amount of renewable power or face a penalty. The "banding" of ROCs was introduced by the UK Government to provide greater funding for newer technologies and by making them more cost competitive, to allow them to develop faster. The Scottish Government have gone even further and modified the ROC scheme so that wave and tidal energy receive greater funding in Scotland, than at UK level. At UK level wave and tidal power receive 2 ROCs per MW/hr but in Scotland wave now receives the equivalent of 5 ROCs per MW/hr and tidal receives 3 ROCs per MW/hr. This enhanced banding is particularly important for the marine energy sector, and may make tidal power comparable in costs to that of onshore wind (Allan et al, 2010c). However, it is not yet clear how this differential incentive is to be funded. Also, in April 2010 a UK-wide feed-in Tariff scheme (FiTs) was introduced to provide support for small-scale electricity generators[22]. The downside of this type of funding for renewables is that most of the high support costs are passed on to consumers in the form of higher energy prices. The Scottish Government also provides support through other schemes, funds and prizes to promote renewables, such as the Saltire Prize.

Overall, there are limited powers available to the Scottish Government to achieve its substantial climate change goal of effecting a 42% reduction in emissions by 2020. Why the Scottish Climate Change Act set an emissions reduction target which differs from the UK target, is not entirely obvious. It does not appear to be purely a supply-side decision as 42% is a very ambitious target that will not necessarily be easily met on current trends and maybe therefore require the purchase of offset credits. It may reflect a political stance in Scotland that is more sympathetic towards environmental objectives. One possibility is that, given the limited instruments available to the Scottish Government, in order to achieve their goals they are seeking to influence authorities, such as the UK Government, that do have more powerful instruments available. By setting the demanding 42% reduction target the Scottish Government may be seeking to influence UK policy.

One possible option would be for the Scottish Government to change the nature of the targets, or supplement them with additional targets focussed solely upon emissions generated within Scottish borders. Although this change goes against the principle of the EU ETS, in which the geographic location of emissions reductions is essentially irrelevant, it would provide a direct measure of emissions reductions within Scotland's borders. Clearly, in this case Scotland's new 80% renewables target may influence actual domestic CO2 emissions, while not contributing to the UK's emissions reduction target.

6. Conclusions and further research

The aspiration of Scottish climate change policy, as expressed in their targets, is world leading. Currently the Scottish climate change framework is more ambitious than the UK counterpart. It includes international aviation and shipping, is independent of the EU framework and it sets annual targets. These make the Scottish framework tougher but less flexible than its UK equivalent. The Scottish targets will be more difficult to achieve but, if achieved, then this framework could provide an appropriate contribution to Scotland's effort towards mitigating global climate change. These targets may also indirectly provide a credible incentive for substantial investment in renewable energy in Scotland,though direct funding for renewables is more appropriate in achieving this goal. If targets are missed regularly they will begin to lose credibility. Then measures such as banking, borrowing, using credits and adopting less frequent targets, should be taken to create more flexibility in meeting the targets. However, it is not clear that the Scottish Government actually has sufficient policy instruments to ensure achievement of its emissions reduction targets.

One major issue currently is that the Climate Change (Scotland) Act does not allow for the contribution of renewables towards the emissions reduction targets. Scotland's electricity sector is part of the EU ETS traded sector and as such emissions that "count" here are not Scotland's actual emissions from electricity generation but their share under the EU ETS. The Scottish Government has other energy policy goals of security of supply, price and economic growth. It has specific policies on achieving growth through renewables, with an 80% renewables target by 2020, and also phasing-out nuclear power, a decision at odds with emissions reductions given nuclear may be a cheap low-carbon option. Scotland has the potential to utilise and create new industries for low-carbon technologies. Large-scale deployment of technologies such as onshore and offshore wind, as well as a marine energy, could help promote a diverse and potentially lucrative renewable energy sector. However, given the current costs, these infant industries will require substantial support and funding from the Scottish and UK Governments through mechanisms such as ROCs. These must be set appropriately to induce the levels of investment necessary to meet the renewables targets. It is likely that costs from increasing renewable penetration will be passed onto consumers in the form of higher energy prices. Carbon capture and storage also has a role to play in helping to limit emissions from dirtier sources and there is also a potential for a growing worldwide industry too. CCS will require substantial development support to make it large-scale and regulation to enforce its adoption but ultimately it is not a long-term option.

Many determinants of emissions are beyond Scottish Government control e.g. energy prices, the EU ETS price and tax raising capabilities reserved to the UK Government. Therefore, should Scotland have its own climate change targets at all? The answer is probably no. Given that they do

however, the Scottish Government must use the powers they have, such as planning permission, encouragement for renewables and efficiency benchmarking in the non-traded sectors, to maximum effect if they are to achieve the targets they have set. Perhaps it could set targets that are more obviously linked to the available instruments, specifically on the non-traded sector. Of course, the absence of instruments does not imply that the targets will not be achieved: they may be but as a consequence of forces outside the Scottish Government's control e.g. a prolonged period of low growth or a warm winter. Therefore it is important to know why and how targets are met. While there is a lack of instruments presently the Scottish Government may seek to exert influence on those that do have the necessary instruments or there may be a possible argument for granting more powers to the Scottish Government by extending the devolution agreement. Another option would be to change or supplement the accounting of emissions within the Scottish framework, to make it those emissions produced within Scotland's border than count towards the target and preferably make sure all GHGs are included within these targets.

This paper is intended to provide a brief summary of the main issues that are specific to climate change policy in Scotland. We think it is far from clear that Scotland currently has the range of instruments that it would require to achieve its own targets. If this is the case then there are only a few solutions. One response may be for the Scottish Government to push for more instruments and this could be done by extending the powers afforded to them through devolution. Another response would be to either reduce the targets and thereby making them easier to meet, or to set different targets that the Scottish Government has more control over. What is quite clear is that it would be useful to extend evidence base relating to the feasibility, and likely costs, of any climate change policies. The CCC and DECC are considering some of these in detail. It would be useful, for example, to develop an energy-environment-economy model of the economy to simulate system-wide effects of changes in policy instruments through to the final goal outcomes.

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Stimulating diffusion of low-carbon technology: evidence from a voluntary program

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Voluntary programs are an increasing part of the environmental policy portfolio. These voluntary programs attempt to reduce environmental impacts through emission reduction pledges, improve the environmental awareness of firms or provide information to the public. A more novel use of voluntary programs has involved the acceleration of technology diffusion of environmentally beneficial technologies to overcome typical problems like lack of technical information, principal-agent problems or to lower the threshold of network externalities. However, this type of voluntary program is what will be needed for firms and councils to comply with the UK Climate Change Act of 2008 and/or the Climate Change (Scotland) Act of 2009. These Acts require medium and large public and private sector institutions to meet an emissions cap that is more stringent than the EU Emissions Trading Scheme.

One technology with a high potential for carbon emission reductions is combined-heat-and-power (CHP), also known as cogeneration. When combustion boilers burn fuels like oil, gas, and coal to spin a turbine for electricity generation, the generated heat usually dissipates without further use. CHP utilizes the excess heat from the combustion process and generates electrical or mechanical power from it. This means that more energy is created with the same amount of fuel. The overall efficiency gains depend on the type of CHP system and fuel used. For example a 5MW natural gas turbine on average increases overall efficiency from 49% to 75% when employing CHP; which is a comparable increase to applications for steam, diesel and gas turbines.

The Intergovernmental Panel on Climate Change considers CHP as a key technology for carbon mitigation due to its improved efficiency. An additional benefit of CHP systems is that it allows for generation to be distributed amongst the consumers, which can increase the efficiency of the electricity generation and distribution system (Strbac, 2008). Improved energy efficiency is a pillar of many governments' policy to reduce greenhouse gas emissions. The International Energy Agency (IEA, 2009) argues strongly for the potential of efficiency improvements to reduce energy use and related emissions. Within the European Union, the 20-20-20 targets for member states are to reduce energy consumption by 20% through increased energy efficiency.

The potential for reduced emissions at low costs has led many countries to introduce policies that encourage CHP adoption. Germany, for example, aims to increase its share of CHP in electricity generation to 25%. A number of U.S. states count CHP as a "renewable" technology in their renewable portfolio standard legislation as well as providing tax credits or grants for the adoption of CHP.

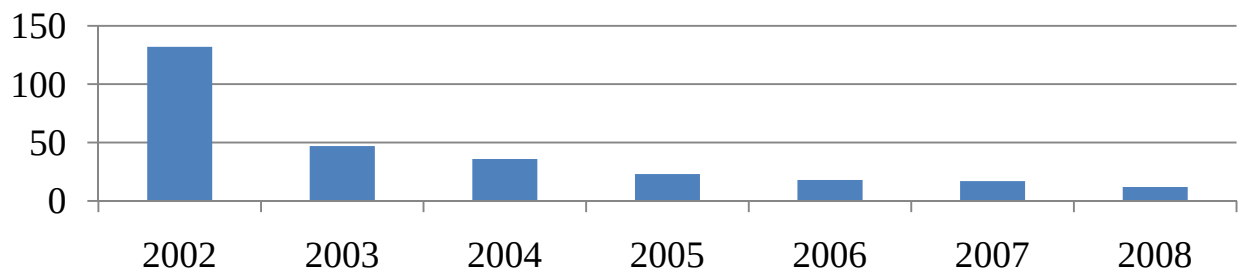
The US Environmental Protection Agency's Combined Heat-and-Power Partnership (CHPP) was established in 2001 and represents this new application of voluntary programs (US Environmental Protection Agency, 2010). Designed as a multi-sector federal voluntary program, it aims to facilitate the diffusion of CHP systems by giving early-stage consulting support to firms, public recognition as well as by providing a platform for contacts and knowledge transfer. Additionally the partnership brings various groups together to promote knowledge about CHP through workshops, conferences and web seminars. Currently there are 369 partners including federal, state and local government agencies as well as private organizations like energy users and producers, service companies, CHP project developers, consultants and manufacturers. When joining, partners agree to designate a liaison for the partnership and to report data on existing and planned CHP projects.

Analysis

Given the goals and structure of CHPP two hypotheses are to be discussed here. The first is whether the partnership has encouraged the installation of CHP applications and the second whether it has assisted knowledge transfers and spillovers that helped to increase CHP utilization. The first question is addressed by applying a conditional logistic probability model on a panel data set for large boilers in the United States. For the second question, we test whether the CHPP facilitates knowledge transfers that increased the efficiency and use of cogeneration in plants which have installed the technology. For this purpose we construct a variable to capture the usage of CHP to test for an increase in utilization and efficiency due to the program. The main data set used for the analysis is the US Energy Information Administration Form 906/920, which comprises a sample of large boilers in the electricity industry for the years 2001 through 2008. Table 1 gives the number of CHP systems installed each year in the data. Since the data start in 2001, we are not able to determine the year CHP systems installed before 2001 are installed.

A conditional logistic probability model estimates the probability of CHP installation at a given plant depending on factors that influence the installation decision. These include partnership in CHPP, the main fuel consumed, plant size, electricity prices, location, state renewable portfolio standards (comparable to Renewable Obligation Certificates

Table 1: CHP installations by year



in the UK), and other support measures at the state level. This probability is estimated for each plant in each year on the condition that the given plant has not installed CHP in a previous period. As soon as a plant has installed, the observations for this plant are dropped from the data set as otherwise the installation decision will be re-evaluated by the model for the next year although the plant already adopted the technology. In this case the estimates would be biased.

The data contain over 2700 plants with almost 1000 of them having installed a CHP system at some point in the sample. As there may be selection bias in the choice of firms to join CHPP, the partnership decision was instrumented for using membership in other voluntary programs, firm size, and number of previous CHP systems installed at the firm. Partnership in CHPP is positively associated with installation, though statistical significance varies with the control variables included. Results also show that smaller coal plants and large gas plants are the most likely plants to install CHP. Higher electricity prices are also associated with installation of CHP systems. Surprisingly, state renewable portfolio standards are found to not statistically alter installation behavior.

Next, the data is analyzed to determine factors that lead to utilization of the CHP system. The model assumes that partnership in CHPP, state renewable portfolio standards, the main fuel consumed, plant size, electricity and fuel prices, and other controls explain utilization. Panel data methods are used since utilization is available for each year that a CHP system is in use.

The hypothesis for the improvement of utilization from knowledge transfers and spillovers due to the program is supported by the data. This utilization analysis, in comparison to the previous method, includes observations only for plants in the data set that have CHP installed. We find that the CHPP has a significant effect on the usage of CHP at partner institutions compared to non-partners. This effect decreases (relative to non-partners) the longer the firm is in the partnership. There could be a number of explanations for this, perhaps all firms learn more about their CHP system as they use it but the partner firms acquire this knowledge quicker than non-partner. At this point we do not know what the reason is for the convergence in utilization among firms. Other factors that also have an influence on the utilization and which serve as controls in the analysis include the following: Plant size, electricity price and state environmental portfolio standards have a positive and statistically significant effect on usage. On the other hand utilization of CHP is negatively affected by the deregulation of electricity markets. Finally, coal plants tend to use their systems more than oil or gas plants.

Voluntary programs which encourage the adoption and diffusion of clean energy technology are of great interest to policymakers. There are many ways to structure such programs, so it is important to consider pathways which lead to diffusion. The CHPP provides partners with information about the benefits of adopting CHP and then provides platforms for those interested to continue exchanging knowledge. Given this framework, two analyses are undertaken to determine whether CHPP has encouraged installation and utilization of the CHP systems in its partners. The findings are generally positive, though not always robust to alternative econometric models and specifications.

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The rebound effect: some questions answered

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Introduction

An overview of the problem of 'rebound' effects

Greenhouse gas (and other pollutant) emissions from energy use are now taken to be a problem both internationally and for individual national and regional governments. A number of mechanisms are being employed to reduce energy consumption demand. A central one is increased efficiency in the use of energy. The Intergovernmental Panel on Climate Change (IPCC) of the United Nations (IPCC, 2007) projects that by 2030 energy efficiency gains will provide a substantial part of the remedy for climate change by reducing global energy consumption to approximately 30% below where it would otherwise be. Such a reduction is argued to be almost sufficient to offset energy consumption increases driven by projected global economic growth. Similarly the widely cited Stern report (Stern, 2007), and the International Energy Agency (e.g. IEA, 2009), attach crucial importance to the potential for efficiency improvements to reduce energy use and related emissions. Within the European Union, one of the EU 20-20-20 targets for member states is to reduce energy consumption by 20% through increased energy efficiency (see, for example, European Commission, 2009). Moreover, the European Strategic Energy Technology Plan (SET-Plan) – see, for example, European Commission (2010) – places energy efficiency at the centre of its Smart Cities and European Electricity Grid Initiatives (among the European Industrial Initiatives (EII)). At the UK level, the UK Energy White Paper (2003) describes energy efficiency as one of the most cost effective and safest ways of addressing energy and climate policy objectives. In Scotland, the recently published 'Energy Action Plan', the Scottish Government sets out Scotland's first national target to improve energy efficiency and how this will be achieved with the use of grants given to local authorities. In the Appendix to this paper, for the reader's information, we provide a summary overview of energy efficiency policy instruments currently active within the UK and Scotland.

However, the straightforward link between increased energy efficiency and reduced energy consumption has been questioned. This is due to the notion of the 'rebound effect'. Rebound occurs when improvements in energy efficiency actually stimulate the direct and indirect demand for energy in production and/or consumption. It is triggered by the fact that an increase in the efficiency in the use of energy acts to reduce the implicit price of energy, or the price of effective energy services for each physical unit of energy used (Jevons, 1865; Khazzoom 1980; Brookes 1990; Herring, 1999; Birol and Keppler, 2000; Saunders, 1992, 2000a,b; Schipper, 2000). The rebound effect implies that measures taken to reduce energy use might lead to increases in carbon emissions, or at least not offset them to the extent anticipated. The question of whether rebound provides a possible explanation as to whether UK energy use at the macro level has not reduced in line with energy efficiency improvements is raised in a report by the UK House of Lords (2005). Following this report, the UK Energy Research Centre (UKERC) conducted a review of evidence on energy efficiency and rebound, published in UKERC (2007), and later in 2007 the UK Economic and Social Research Council, ESRC, funded the current project to investigate economy-wide rebound effects using multi-sectoral computable general equilibrium (CGE) modelling techniques. Previous non-technical papers on the key findings of this research, published in the Fraser Commentary and in the Welsh Economic Review, can be found in Turner (2009b), Turner et al et al (2009, 2010).

The purpose of the current paper is to clarify some issues relating to the phenomenon of rebound effects. The paper originates from an interview with the Principle Investigator, Dr Karen Turner (University of Stirling, formerly of the University of Strathclyde) by Maggie Koerth-Baker, a science journalist working on a book for Wiley & Sons about the future of energy in the United States. The following is not a precise transcript of that interview; rather it picks out and develops key issues from the questions posed and the answers given.

MKB (Question). My understanding, after doing some reading, is that the situation that led to Jevons' famous observation (the Jevons Paradox – see Jevons 1865;

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Brookes, 1990) was a little more complicated than simply an issue of one technology improvement directly lowering price of coal, which directly increased use. That is, there were specific applications of the improved engine that really mattered to the effect and a lot more factors going into it. Is my understanding correct? And how does that impact debates about backfire/Jevons Paradox today?

KT (Answer). There are two important points here. First, rebound is basically driven by the change in an *implicit or effective* price, not an actual market price (though this may be affected as well). Jevons's basic point was that if we increase the efficiency with which we use any factor of production, we lower its implicit price. That is, in the case of energy, we get more energy services from a given input of energy, thereby lowering the price of the former, if not the latter. This, like any price change, will trigger a positive demand response and it is the strength of this demand response both directly and indirectly (knock on effects throughout the economy) that gives us rebound. Thus, rebound occurs as a result of the upward pressure on demand for energy, which will partially or even wholly offset the initial efficiency effect (decreased demand as less energy is required to maintain a given level of production or consumption).

Therefore, the change in the implicit price of energy when efficiency is improved in its use is what triggers both direct and also economy-wide rebound effects (the former affecting the change in energy use by the producer or consumer whose efficiency has increased, the latter affecting what happens to energy use at the economy wide level). The key point is that the implicit price change is the source of rebound effects. The complications come in terms of just how that implicit price is affected by an energy efficiency improvement. For example, factors such as the costs involved in implementing an efficiency improvement may limit the fall in the implicit price.

A second issue is that Jevons seemed to be more concerned about the extreme case of rebound, commonly referred to as 'backfire', where the demand response to the change in the implicit price of energy is so strong that there is a net increase in energy use. This is a less likely outcome than partial rebound, but it is an important one, because it entirely negates the energy (and pollution) saving properties of energy efficiency improvements (if not the economic benefits). Therefore, it is important to investigate the circumstances under which rebound may grow into backfire and to consider any complicating factors.

MKB (Question). My understanding is that a lot of the evidence for full backfire comes from economic modeling using computable general equilibrium (CGE) as a basis. Skip Laitner at the American Council for an Energy Efficiency Economy (ACEEE) has some interesting criticisms of that basis (see Laitner, 2000), in particular that it assumes purely rational behaviour that we don't actually see in real-life consumers, and thus isn't likely to show real-world applicable results in a model. I'm curious about your perspective on that.

KT (Answer). Again, there are two issues here. First, it is not only CGE models that generally assume rationality. However, it is possible to build in representation of, for example, irrational or habitual behaviour into economic models – for example, treatments of inertia that prevents uptake of energy efficiency improvements and/or changes in behaviour in response to changes in prices - where it is appropriate or useful to do so. More generally, if behaviour is affected by factors such as bounded rationality, imperfect information, it is important to understand such behaviours and identify appropriate analytical frameworks.

Secondly, yes, rebound will grow when we take a wider range of economic responses into account, as we do in considering economy-wide rebound effects. However, our evidence for backfire (a net increase in energy use when efficiency improves) is quite limited. In the case of Scotland, we find that backfire only tends to occur when we have increased energy efficiency in the relatively highly energy-intensive energy supply sectors, particularly where trade and competitiveness effects are important (see Turner et al, 2009; and Turner, 2009b). Generally, backfire requires an economy-wide (direct and derived) demand response that is highly responsive (more that proportionate) to the initial implicit price change.

MKB (Question). The studies that look at specific technology areas (home heating or personal transportation) and at direct rebound in those areas show reasonably low rebound effects, usually on the order of 10-40% or so, looking at some reviews done by Steve Sorrell (e.g. Sorrell led the UKERC, 2007, study). Why are those so different from what CGE modelling studies come up with? Is it simply a factor of not looking at indirect or economy-wide effects?

KT (Answer). As explained in the last answer, indirect and/or economy-wide effects will add to the size of rebound. Moreover, economy-wide rebound effects will depend on the nature and structure of the economy in question (what type of supply and demand linkages, presence of local energy supply etc). Therefore, there is no implication that results of micro and macro studies are inconsistent. In some cases, the direct effects will dominate. For example, one piece of work in our project (carried out with Sam Anson from the Scottish Government) involved investigating the impacts of increased energy efficiency in the Scottish commercial transport sector (Sam wrote his MSc dissertation in this area, which we then developed into a paper – see Anson and Turner (2009) and also Turner et al (2010). Here we found that, aside from some key impacts on the Scottish refined oil supply sector, economy-wide rebound effects were not very big. Instead, the own sector effects (energy use within the Scottish commercial transport sector itself)

dominated and our rebound estimates were similar in magnitude to what had been found in micro studies.

MKB (Question). Is it possible to measure direct rebound in reality in a more accurate way? What would we have to know in order to do that? What about indirect? It seems almost impossible to tease out of all the different variables and unknowns?

KT (Answer). Many studies use econometric techniques to examine the key relationship for direct rebound, which is the price responsiveness (or price elasticity) of demand in response to the change in the implicit price of energy. CGE studies also use empirical techniques to consider economy-wide rebound. However, in specifying CGE models, knowledge of the responsiveness of direct and indirect (derived) demands to changes in the implicit price of energy, and the knock on effects on other prices (e.g. the actual price of output in sectors where there is an efficiency improvement will fall) is crucial. This can be problematic (see Turner, 2009a) and is a focus of our continued research in this area.

However, the key issue is understanding causality. This won't just be in terms of changes in prices and demand. Speaking to UK policymakers at the UK Department of Energy and Climate Change, DECC, we understand that the gap between expected and actual energy savings when energy efficiency increases will not only be due to rebound[1]. There will also be issues such as whether equipment works as anticipated (i.e. in terms of the desired efficiency improvement actually being realised). Therefore, it is important to consider all the causal process that may occur in response to an increase in energy efficiency, whether they only partly delay its implementation, or whether there are likely to be lasting rebound effects as prices (and incomes) change throughout the system.

In terms of disentangling effects, this can be difficult because different effects will be interdependent. For example, if energy efficiency improves in production the first (and direct) response to the resulting fall in the implicit price of energy will be a substitution effect away from other inputs in favour of energy. This allows the price of output to fall in that sector and the other sectors that purchase its outputs as inputs to their own production. This in turn triggers positive competitiveness effects, which further stimulate rebound (as activity levels increase) and also GDP growth. However, if the initial substitution effects are weak, this will limit the size of the positive competitiveness effects, and so on.

MKB (Question). In your work, you mention several issues in modelling and calculating rebound/backfire effects that aren't widely taken into account, like supply side responses. Are there other factors that aren't being widely considered? Do these unconsidered factors tend to push more towards full backfire or away from it?

KT (Answer). The focus of our research on this project has been to consider the economy-wide effects that impact on the rebound effect. However, while the wider literature has tended to focus on the additional demand responses to the price (and income effects) that drive rebound, our research on the ESRC First Grant has had something of a more novel focus by investigating the importance of supply-side effects. We have looked at two types of supply-side effect. First, we have focussed in all our analyses on the role of labour and capital markets in allowing the economy to expand (or not), thus making them important determinants of economy-wide rebound.

Second, we have also looked at the response of local energy supply sectors. We have looked at two specific effects here. First, where there is local supply of energy in the form of, for example, locally generated electricity or locally refined oil, the initial reduction in demand for energy in response to increased energy efficiency (as less energy is required to maintain a given level of production or consumption) will put downward pressure on the actual as well as the implicit price of energy. This may cause what we have referred to as 'disinvestment' effects (Anson and Turner, 2009; Turner, 2009a; Turner et al 2010). To explain, if demand is sufficiently responsive, then any decrease in actual energy prices will exacerbate rebound. However, if demand is not sufficiently responsive, then revenues and profits will fall in local energy supply sectors, which will lower the return on capital and cause a contraction in capacity in these sectors. This tightness in local energy supply will drive output prices back up, and this will act to constrain rebound over the longer run.

We have also found that as a result of the initial contraction in demand for energy as efficiency increases, negative multiplier effects may also act to offset *economy-wide* rebound, potentially to the extent that energy savings at the macro level are larger than may have been anticipated. Negative multiplier effects occur because as demand falls for the output of local energy supply sectors less inputs are required to produce a lower output level. This will trigger negative multiplier effects back down the supply chain (in the production sectors where outputs are used as intermediate inputs to production). Given that energy supply sectors tend to be relatively energy-intensive, these negative multiplier effects are likely to be particularly important in energy supply itself (see Turner, 2009a). The key issue is whether negative multiplier effects are large enough to entirely offset rebound effects so that total energy use in the economy contracts. In our research we have found evidence for such 'negative rebound' effects at the UK level. However, negative multiplier effects seem to be of less importance in the Scottish case, probably due to the greater trade in energy (which stimulates demand to a greater extent as prices fall).

Another important issue that has emerged from our research (and one which we have only recently begun working on) is that there is a difference in terms of how

energy efficiency improvements in consumption activity (such as household energy use) transmit to the wider economy relative to what happens if efficiency increases in production. In the latter case, increases in the efficiency with which any input is used will act as a productivity increase, stimulating competitiveness and GDP along with energy use. That is, it takes the form of a positive supply-side shock. However, in the case of household use of energy, increased efficiency acts a demand disturbance. The disinvestment and negative multiplier effects abo e are again important as reduced demand for energy in the household sector, and in the wider economy as the demand contraction spreads, will impact on revenues and activity levels in local energy supply. However, the net impact on economic activity in general and energy use in particular depends on how households spend the money that they save as they increase energy efficiency. If they demand more energy, rebound will grow, but if they demand other, non-energy, goods and services then the economy may grow with more limited rebound (see Druckman et al, 2009, for research into the issue of how households may redirect their spending). However, demand shifts change prices throughout the economy, with the implication that domestic demand may crowd out export demand (where there is upward pressure on prices).

MKB (Question). You mention in your work that rebound and backfire effects vary by technology and location and have to be considered on individual policy decision basis. Why would it vary by location? Don't consumers behave fairly similarly throughout the Western world?

KT (Answer). It may be that direct rebound may be expected to be similar among consumers across the Western world (though even within a single country things like income levels will matter). This is because direct rebound is likely to depend largely on behavioural responses. However, indirect and economy-wide rebound effects depend on the structure of economic activity. For example, when we have looked at Scotland and the UK, even where we set up our model so that parameters governing direct rebound (e.g. how producers substitute between energy and other inputs in production in the sector targeted with the efficiency improvement) are identical, we get quite different economy-wide rebound effects. This is due to the different structure and composition of economic activity at the economy-wide level in general, particularly (but not exclusively) the importance and openness to trade of the Scottish energy supply sectors relative to their national counterparts.

MKB (Question). What does all of this mean for the idea that we can use efficiency to mitigate the economic impact of combating climate change? Does rebound effect necessarily kill ideas of decoupling economic growth from GHG emissions?

KT (Answer). No. Only the extreme case of rebound (backfire) where there is a net increase in energy consumption in response to increased energy efficiency will cause energy use and related emissions to rise with GDP. Where rebound is less than 100% (which is most cases in our work and in the wider literature), this means that we will not realise one for one energy savings in response to an efficiency improvement. Particularly, where increased energy efficiency takes place in on the production side of the economy (so that it takes the form of a productivity improvement), even some reduction in energy use produces what we may refer to as a ‘double dividend’: increased economic growth with falling pollution levels. Generally, where energy efficiency improvements lower prices and improve competitiveness, and so long as we do not encounter increased energy use and emissions through backfire, this must be a positive outcome. However, the GHG emission issue is of course an important one in the context of rebound and provides an important context for further research. We have begun to look at this in particular in a new paper that is forthcoming in Energy Economics (Turner and Hanley, 2010).

MKB (Question). What role can coupling energy efficiency technologies with automation play in reducing direct rebound effects? For instance, if I get a more energy efficient heater, but I have it linked up with programmable thermostats aren't I less likely to end up using more heat?

KT (Answer). This is a very important issue. In the current project we haven’t got to the point of looking at specific technologies. However, rebound properties of any specific energy efficiency improvement will depend not only on costs of introducing efficiency improvements, but also on how well energy users are able to recognise and respond to the implicit price change. For example, if a household purchases a more energy efficient fridge, the price effect is automatic and will be reflected in the next electricity bill. On the other hand, if a household installs loft insulation, they need to undertake further activity, such as appropriate adjustments to thermostats/heating controls, before the efficiency improvement and subsequent price effect are realised. We’ve identified this type of issue as a core focus for future research (we have an application with colleagues at the Universities of Stirling and Strathclyde, most of whom are contributors elsewhere in this special issue, submitted to the European Research Council to continue our rebound research into a number of the areas discussed here).

MKB (Question). What role can coupling energy efficiency technologies with information play? I'm thinking, in particular, about computer feedback systems designed to show you how much energy you're using compared to various times in the past. Do we know how people respond if they're made aware of the fact that they're rebounding?

KT (Answer). Again, I think this is a very important question, and it links back to the previous one. In the examples given above, people find out quite quickly about the savings they

make from installing a more energy efficient fridge, so this is the point at which they will make decisions on how to use the income freed up from their electricity bill. Therefore it is also a point at which information may be useful to them about the implications of rebounding by using more energy (and perhaps incentives put in place to prevent them from doing so). However, in the other example, where people have to adjust their behaviour after they install loft installation, there is also the issue that (due to a combination of habit and lack of information) they may continue to spend too much on heating (i.e. not realising the full energy savings that are possible, and/or getting to the point of rebound). In such circumstances technologies such as smart meters may help people make informed decisions to adjust their behaviour and realise potential energy savings. The bigger job is influencing how they spend the funds freed up when efficiency improves. There may be a role for policy here. For example, also on the production side of the economy, incentives may be required to induce energy users to realise the full energy savings that are possible (especially when it may lower total consumption/production costs to use more energy, given that its implicit price has fallen).

MKB (Question). Cap and trade and carbon taxes have also been discussed as a way to counteract rebound effect. Do you see one or the other as being more effective in this way? Also, when we use these policies we're basically setting incentives for people to use less energy. The cheapest way to use less energy is efficiency. Why doesn't that stall rebound or backfire even under these policies?

KT (Answer). Basically anything that offsets the decrease in the implicit price of energy that triggers rebound will act counteract it. However, there are two important issues to consider. First, particularly in production, where the lowering of the implicit price of energy triggers a productivity improvement, rebound is not necessarily a bad thing (only the extreme case of backfire increases energy use and emissions). It just means we have to work harder at achieving desired energy savings (e.g. energy efficiency targets may have to be proportionately larger than energy reduction ones to allow for rebound). If there is a need to prevent rebound, taxes are a possibility. However, carbon tax is perhaps a bit too indirect, that is it would be better to focus directly on the energy use where the price change occurs. Revenues could be partly used to bring energy efficiency improving technologies to the market (this is already done in the case of the UK Climate Change Levy). Nonetheless, taxes are distortive and it is difficult to design an optimal tax to address something as specific as the change in energy prices as a result of efficiency improvements (particularly where actual as well as implicit prices change). Before taking such a step, and to preserve the full economic benefits of improved efficiency, it would be useful for policymakers to consider the type of information issues discussed above. That is, try to help people understand the issues involved and encourage them to adjust their own behaviour voluntarily.

Closing comments

The objective of this paper has been to use the Q&A format of the interview designed by Maggie Koerth-Baker to communicate key issues regarding the rebound effect and key findings from the ESRC First Grant project in a non-technical manner. A full set of outputs from the project can be found on the ESRC Today web-site URL below). However, interested readers may address questions directly to Karen Turner at karen.turner@stir.ac.uk.
http://www.esrcsocietytoday.ac.uk/esrcinfocentre/viewawardpage.aspx?awardnumber=RES-061-25-0010

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Endnote

[1]The project team made a presentation on energy efficiency and rebound effects to the Department of Energy and Climate Change (DECC) on Monday 20th September 2010. Following the presentations, a round-table discussion was held with DECC analysts.

Appendix

Summary of energy efficiency policies in the UK

The Sustainable Energy Act 2003 required the UK Government to publish a statutory aim for residential energy efficiency in the UK. This requirement was fulfilled in the 2004 Energy Efficiency Action Plan, which set out to save 3.5 million tonnes of carbon per year by 2010 through energy efficiency measures in the household sector. The range of measures implemented by the UK Government are summarised below.

Table A.1 Policy levers and examples of energy efficiency policies

Levers to Reduce Household Energy Consumption	
Instrument	**Examples**
Regulation	**Building Regulations, The Home Energy Conservation Act 1995**
Grants and Fiscal Incentives	**Code for Sustainable Homes, Energy Efficiency Commitment, Carbonn Emissions Reduction Target, Supplier Obligation,, The Warm Front Scheme, Improving the energy efficiency of our homes and buildings**
Information and Awareness Raising	**Energy Certificates and air-conditioning inspections for building, Supplier Obligation (metering and labelling), Energy Saving Trust programmes, Energy Performance Certificates, Labelling, Billing and Metering**

Regulation

Building Regulations (England and Wales) 2002

Building Regulations (England and Wales) 2005/6

Part L of the regulatory building framework sets the standards for energy efficiency measures and practices in the construction of new domestic buildings and for improvements to existing buildings. For energy efficiency measures contained in the building regulations see the link below.
http://www.communities.gov.uk/documents/planningandbuilding/pdf/Energyefficiencyrequirements.pdf.

The Home Energy Conservation Act 1995

The Home Energy Conservation Act 1995 requires all UK energy conservation authorities to prepare an energy conservation report indentifying cost effective measures likely to result in the energy efficiency of all residential accommodation in their area.

Grants and fiscal Incentives

The Code for Sustainable Homes and the Energy Efficiency Standard for Zero Carbon Homes

The Code for Sustainable Homes (the Code) is the national standard for the sustainable design and construction of new homes. It applies in England, Wales and Northern Ireland. The Code goes further than the current building regulations, but is entirely voluntary, and is intended to help promote high standards of sustainable design. The Code sets minimum standards for energy and water use at each level and, within England, replaces the Eco Homes scheme, developed by the Building Research Establishment (BRE).

http://www.communities.gov.uk/planningandbuilding/sustainability/codesustainablehomes/

http://www.communities.gov.uk/documents/planningandbuilding/pdf/1415525.pdf

The Warm Front Scheme
Warm Front (the Scheme) is a key programme of the Department of Energy and Climate Change (the Department) to tackle fuel poverty by improving energy efficiency in privately owned properties in England.
http://www.nao.org.uk/publications/0809/the_warm_front_scheme.aspx

CRC Energy Efficiency Scheme

The Carbon Reduction Commitment Energy Efficiency Scheme (CRC) is the UK's mandatory climate change and energy saving scheme. It has been designed to raise awareness in large organisations, especially at senior level, and encourage changes in behaviour and infrastructure.
http://www.decc.gov.uk/en/content/cms/what_we_do/lc_uk/crc/crc.aspx

Carbon Emissions Reduction Target (CERT)

The Carbon Emissions Reduction Target (CERT) requires all domestic energy suppliers with a customer base in excess of 50,000 customers to make savings in the amount of CO2 emitted by householders. Suppliers meet this target by promoting the uptake of low carbon energy solutions to household energy consumers, thereby assisting them to reduce the carbon footprint of their homes.
http://www.decc.gov.uk/en/content/cms/what_we_do/consumers/saving_energy/cert/cert.aspx

Supplier Obligation

The Supplier Obligation instrument developed by DEFRA gives suppliers and consumers a shared incentive to reduce carbon emissions from homes. As a way of providing feedback on household energy use directly to each household, 'smart' meters have been introduced. A 'smart' meter replaces the existing meter which can constantly monitor energy use and costs. From the supplier perspective, the smart meter provides the energy supplier with direct feedback on energy use through smart communication channels. This means that meters no longer have to be read manually.

Supplier obligation requires that the supplier provide detailed information where possible (for example on utility bills) to highlight where energy savings and improvements can be made.
http://www.sd-commission.org.uk/pages/supplier-obligation-project.html

Information and Awareness Raising

Improving the energy efficiency of our homes and buildings: Energy Certificates and air-conditioning inspections for building

The range of initiatives introduced from January 2009 to help improve the energy efficiency in buildings and meet the UK's carbon emissions. It covers: energy performance Certificates (EPCs) for homes and buildings; display Certificates for public buildings; inspections for air conditioning systems.
http://www.communities.gov.uk/documents/planningandbuilding/pdf/714826.pdf

The Energy Saving Trust (EST)

The Energy Saving Trust (EST) is funded by the UK Government to support household energy efficiency activities. The EST has several core activities directed at household consumers, for example:

1. Implementing Energy Efficiency Advice Centres (EEACs) which provide advice to consumers and help them to assess their energy use and refer them on to any available grant offers.

2. The Sustainable Energy Network (SEN) designed by the EST as a key delivery route for more effective advice to consumers, engaging proactively and enabling individuals to make personal commitments to reduce carbon. In addition to energy efficiency, SEN's will promote carbon saving through renewables and transport.

3. On-line Home Energy Checks – a personalised report showing consumers how much energy and money they can save in their home.

4. The *Save Your 20%* consumer marketing campaign, which is a source of information and call to action for consumers to reduce their energy use and install energy efficiency measures.

5. Accreditation of products under the Energy Saving Recommended label. This directs consumers to products that save the most energy and maintenance of an on-line searchable database of energy efficient products.

6. For local authorities and registered social landlords, EST administers a number of programmes including Practical Help which is a tailored source of information and support on delivering energy efficiency to their communities.

Labelling

From an industry perspective the UK continues to work closely with the EU commission, supporting a mandatory labelling scheme which requires domestic appliances to display energy information. This applies to household refrigerators and freezers, washing machines, electric tumble dryers and air conditioning units. As well as statutory labelling the UK Government is also encouraging voluntary actins by industry to provide customer information as an alternative to enforced regulation.

From a household perspective the UK Government promotes metering and billing schemes which aim to raise awareness about energy use in the domestic sector to the domestic sector. With the support of energy suppliers and in line with the measures stated in the Energy White Paper , consumers are aided to better understand more about their energy use.

Energy Efficiency Policies from the Scottish Government

Scotland

The Scottish Government is committed to reducing carbon emissions in line with the UK targets and also to meet the Scottish Climate Change Target to reduce emissions by 80% by 2050. As well as implementing policies and measures set at the UK level the Scottish Government has also implemented strategies and measures specific for Scotland.

Some Scottish measures are implemented in the same fashion as those at the UK level. For example, raising household awareness and giving advice is in the hands of the Scottish Energy Saving Trust (EST).

A short overview of the Scottish Government's approach to energy policy is available from the link below.
http://www.scotland.gov.uk/Resource/Doc/237670/0065265.pdf

As well as the measures outlined in the document above, two agendas published by the Scottish Government outline the measures and instruments specific to Scotland that will be used to achieve energy efficiency and climate change targets. The links to these published agendas are given below.

Conserve and Save: Energy Efficiency Action Plan

Scotland's first national target to improve energy efficiency will consist of £10 million in grants to local councils to offer free insulation measures and provide energy saving advice to 100,000 households. Scotland's Energy Efficiency Action Plan includes a headline target to reduce total energy consumption by 12 per cent by 2020.
http://www.scotland.gov.uk/Resource/Doc/326979/0105437.pdf

The Low Carbon Economic Strategy

The Low Carbon Economic Strategy (LCES) is an integral part of the Government's Economic Strategy to secure sustainable economic growth, and a key component of the broader approach to meet Scotland's climate change targets and secure the transition to a low carbon economy in Scotland. The Strategy has been developed with, Scottish Enterprise, Highlands and Islands Enterprise, Transport Scotland, Scottish Environment Protection Agency, Scottish Development International, Scottish Funding Council, Skills Development Scotland, Visit Scotland and COSLA.
http://www.scotland.gov.uk/Resource/Doc/331364/0107855.pdf

Preferences for Energy Futures in Scotland

Elena Tinch and Nick Hanley (Stirling Management School, Division of Economics, University of Stirling)

Abstract

In the next two decades Scotland is facing tough greenhouse gas emissions reduction targets as well as the upcoming shutdown of a number of existing thermal plants. Given the limited timeframe it would seem imperative that Scotland's energy policy is developed with public preferences in mind, as political unpopularity and public objections, with the associated need for lengthy public enquires, are likely to mean that targets are more likely to be missed. As such, appraisal of any potential energy option should not be limited to consideration of financial viability but should also take full account of environmental and social costs. The primary aim of our study was to determine public preferences and willingness to pay for alternative energy options, such as wind, nuclear and biomass against the current generation mix, all of which may form an integral part of the future generation portfolio for Scotland.

One method of determining social costs is through stated preference techniques, one of which is choice experiments – the method applied in the current study. Our analysis is based on a postal survey sent out to a random sample of 1000 households across Scotland. People were asked to choose between four energy options: wind, biomass, nuclear and current energy mix, depending on which energy option and associated mix of attributes they prefer. Attributes were: distance from respondent's home, carbon emissions reduction, local biodiversity impacts, land requirements (a fixed attribute) and an annual electricity bill increase (the cost attribute). Our results suggest that carbon-neutral energy options tend to have a positive willingness to pay associated with them and be more favoured by the population over the current energy mix with distance from the respondent's home, increases in biodiversity and increases in energy bill all having a significant impact on preferences. We also found variation in preferences according to socio-economic groupings, for example respondents with children tend to have a higher preference towards renewable technologies than those without.

In addition to the overall sample, we also investigated divergence in preferences between three areas of Scotland (Highlands and Islands; Central; and South). The results indicate that, depending on the geographical location, people's preferences for energy generation technologies vary. Our results suggest that Scottish energy policy need not only be planned accounting for public preferences for different energy options but also regional divergence of preferences within the country.

1. Introduction

Energy policy is one of the central issues of the global political agenda. A widely accepted need for greenhouse gas reduction in combination with security of supply concerns and ever increasing fuel costs means that the development of a cost-effective low-carbon energy portfolio has become a vital challenge for most countries worldwide, to which Scotland is no exception.

This paper attempts to identify public preferences towards energy generating options in Scotland. We investigate public attitudes towards three energy-generating options (energy from wind, nuclear power and biomass) and compare them with the current generation mix. All of these options have the potential to become a major part of Scotland's future low-carbon generation portfolio, so it is important that public preferences and social costs associated with them are considered and properly understood.

This study uses a stated preference approach, namely a choice experiment to achieve the above objective. A number of choice experiment studies have been carried out worldwide looking at public preferences towards various energy-generating options, e.g. Ek (2005) for Sweden, Fimereli et al. (2008) for South-East England, Kataria (2009) for Sweden, Alverez-Farizo (2002) for Spain, Meyerhoff et al. (2009) for Germany, Navrud (2007) for Norway and Krueger et al. (2010) for the US. Much less, however, has been published to date with regard to public attitudes towards energy-generating options in Scotland. Perhaps the most relevant recent publications on this topic are the papers by Bergmann et al. (2005) investigating renewable energy investments in Scotland and a follow up paper published in 2008 by the same author looking at rural versus urban preferences for renewable energy in Scotland.

Our study specifies the energy options as part of a labelled choice experiment, to capture public preferences between the technologies and includes a nuclear option as part of a low-carbon generation mix. This is something that to our knowledge hasn't been carried out in Scotland before.

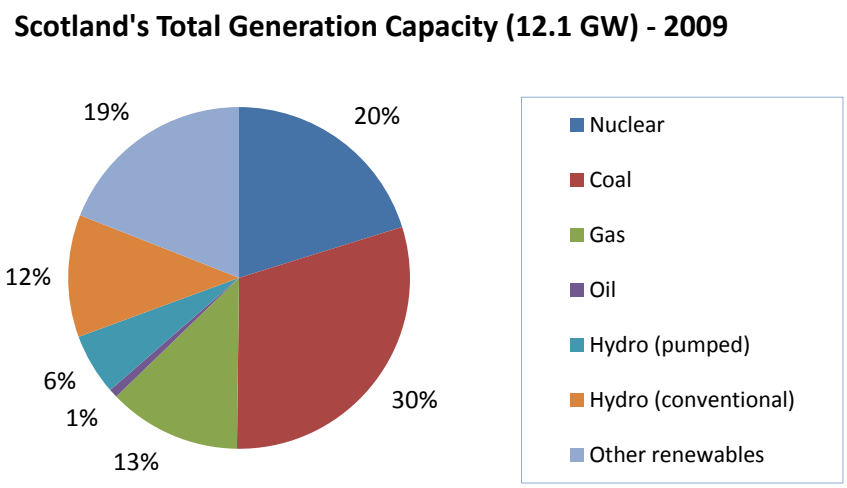
The remainder of the paper is organised as follows: Section 2 gives a brief summary of Scotland's energy policy and current generation mix. Section 3 outlines the methodology and theoretical framework, Section 4 describes the design of the current study and discusses attributes and levels in more details. Section 5 presents the results and findings and, finally, Section 6 concludes the paper with a final summary of the research and a discussion of further research and potential policy implications.

Scotland's energy policy and current generation mix study design

By 2020 the European Union is committed to reduce its carbon emissions by 20% compared to 1990 levels and to generate 20% of energy from renewables. Strict targets were also put forward by the recently published 'UK Low Carbon Transition Plan – National strategy for climate and energy', which sets out a plan for the UK to reduce its carbon emissions by 34% by 2020 on 1990 levels (White Paper, 2009). The Climate Change Bill passed by the Scottish Parliament in 2009 adopted even more ambitious targets to reduce greenhouse gas emissions by 80% by 2050 with an interim target of 42% by 2020.

The power generation sector is the largest producer of carbon dioxide emissions in Scotland accounting for around 50% of total emissions (Wood Mackenzie, 2009). As can be seen in Figure 1, Scotland currently has 12.1 GW of generating capacity, consisting of 3.6 GW of coal generation (Longannet and Cockenzie), 1.5 GW of gas (Peterhead), 2.4 GW of nuclear power (Torness and Hunterston B) and about 3.7 GW of renewable generation (source: Scottish Renewables, 2010).

Figure 1:



Source: Wood Mackenzie, Scottish renewables, Scottish Government.

Major changes, however, are scheduled to happen to the Scottish generating portfolio in the next two decades. One of the two remaining Scottish nuclear plants, Hunterston B is due to be decommissioned by 2015 at the latest, followed by Torness (due to be retired in 2023) (Scottish Energy Study, 2006). Additionally, Scotland's major coal-fired power station Cockenzie has opted out of Large Combustion Plant Directive (LCPD)[1] and will be shut down by the end of 2015 (BERR, 2007). As can be seen from Table 1, assuming no new-built and no further developments and consents to extend stations life, all existing Scottish thermal plant could be phased out by 2030.

All of the above has lead to an urgent need for development of the country's energy policy to fill the upcoming energy gap. Given the limited timeframe available to achieve the Scottish Government's targets it would seem to be imperative that policy is not politically unpalatable to the public, since this would result in the need for extensive public consultation, objection and enquiries. Thus appraisal should not be limited to consideration of financial viability but should also take full account of environmental and social costs. Therefore the current research aims to identify social preference for different future energy options.

3. Methodology and theoretical framework

There are two branches of non-market goods valuation: revealed and stated preferences methods. Revealed preference methods estimate value of a non-market good by studying actual (revealed) preferences. The two most commonly used examples of revealed preference methods are travel cost method and hedonic price method (see Braden and Kolstad, 1991). This branch of methods has been quite popular in non-market goods valuation, but also has a number of drawbacks, amongst which is impossibility of estimation of non-use values (Alpizar et al, 2001), more specifically social costs associated with a particular energy option in our case. Equally there are issues with using revealed preference for future policy analysis in that what you want to value does not yet exist so there is nothing against which to "reveal preferences". The other branch of non-market goods valuation methods, and the one which is appropriate to the current research, is stated preference approaches. This technique assesses individuals' stated

Table 1: Major Scottish power plants, 2009

Station	Type	Capacity, GW	Assumed Closure Date
Cockenzie	Coal	1.2	2015
Longannet	Coal	2.4	2020
Peterhead	Gas	1.5	2025
Torness	Nuclear	1.25	2023
Hunterston B	Nuclear	1.19	2011
Cruachan	Pump storage	0.4	-
Foyers	Pump storage	0.3	-
Several	Hydro	1.4	-
Several	Wind	2.1	-
Several	Other renewables	0.2	-

Source: Scottish Energy Study, 2006

behaviour in a hypothetical setting (Alpizar et al, 2001). Some examples of stated preference techniques are conjoint analysis, contingent valuation and choice experiments (for a review see Hanley, Mourato and Wright, 2001).

Choice Experiment techniques (CE) draw their roots from traditional microeconomic theory whereby consumers are asked to maximise their utility subject to their budget constraint (Eck, 2005). CEs are based upon the characteristics theory of value (Lancaster, 1966), and the random utility theory (McFadden, 1974; Manski, 1977). The theory behind choice modelling is well described and reviewed by many authors, such as (Adamowicz et al. 1995, Hanley et al. 2001, Louviere et al, 2000, Eck, 2005, Birol et al., 2006), and the remainder of this section draws heavily upon this literature.

The fundamental assumption of choice experiments is closely related to hedonic analysis in that consumers derive utility from the different characteristics of a good rather than from the good itself (Lancaster, 1966). The utility function can be specified as:

$$U_{ij} = V_{ij}(X_{ij}) + e_{ij} = bX_{ij} + e_{ij}.$$

Where Uij – is the utility to the individual i, derived from alternative j. In accordance with the random utility framework the utility function is decomposed in two parts: a deterministic part (V), which represents observed influences and a stochastic part (e), representing unobservable impacts on individual choice. X is the linear index of observable attributes and socio-economic and policy characteristics interacting with these attributes while b is a vector of utility parameters to be estimated.
The probability that a respondent prefers alternative "g" in the choice set to an alternative "h", can be expressed as follows:

$$P[(U_{ig} > U_{ih})\forall h \neq g] = P[(V_{ig} - V_{ih}) > (e_{ih} - e_{ig})].$$

To calculate this probability, distributions of the error terms (eij) should be assessed. It is generally assumed that error terms are independently and identically distributed and therefore the probability of an alternative g being preferred over an alternative h can be expressed in terms of a logistic distribution (McFadden 1973, Hanley 2001):

$$P(U_{ig} > U_{ih},\ \forall h \neq g) = \frac{\exp(\mu V_{ig})}{\sum_j \exp(\mu V_{ij})}$$

Once the model has been estimated and if a cost attribute is present in the model, implicit prices or marginal willingness to pay (WTP) for a change in attribute can then be calculated. This is simply done by dividing a non-monetary attribute (for example % reduction in carbon emissions) by the monetary (cost) attribute with a negative sign (see for example Alpizar et al. 2001 for more details).

One of the difficulties with using the standard conditional logit model is the existence of 'independence from irrelevant alternatives' (IIA) property, stating that relative probabilities of two options being selected must be unaffected by the introduction or removal of other alternatives (see Luce 1959). If a violation of the IIA hypothesis is observed, then alternative statistical mixed logit models need to be explored, such as the random parameters logit model (Train, 1998, Hanley et al. 2001), nested logit model or error component model.

Study design

Our study attempts to estimate public preferences and willingness to pay for alternative energy options, such as wind, nuclear, biomass and the current generation mix (status quo option), all of which may form an integral part of future generation portfolio in Scotland. It is a collaborative effort between colleagues from Imperial College London and The University of Stirling and as such the piloting of the survey and two focus groups interviews were carried by Imperial College London (Fimereli et al, 2008). The next section describes in more detail the study design and implementation stages: i) survey structure; ii) defining levels

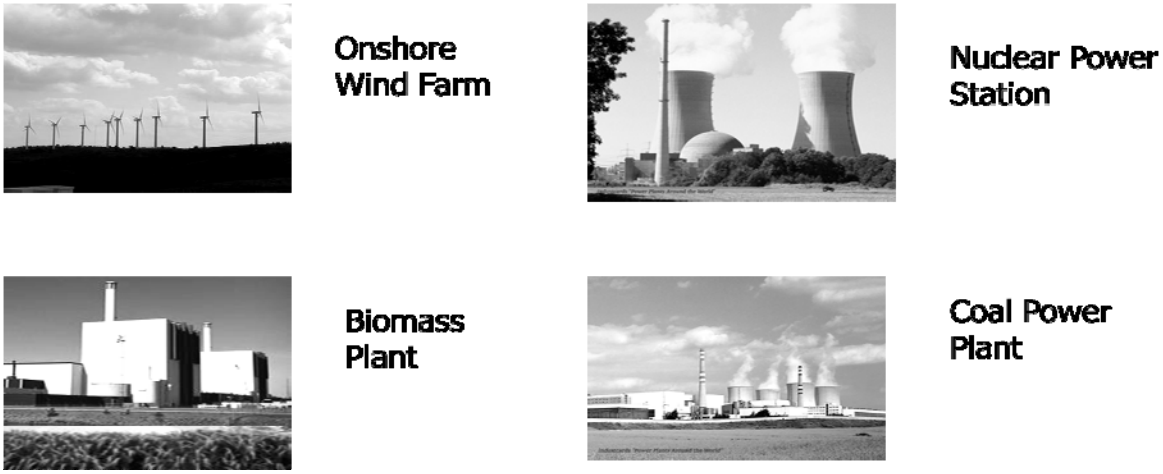
and attributes; iii) choice scenario; and iv) sample selection, strategy and questionnaire logistics.

4.1 Survey structure

Respondents were presented with a mailed questionnaire survey and a letter stating the reasons behind the survey. It was also explained that the survey was entirely confidential and voluntary. The questionnaire consisted of three main parts:

- Part A: "Energy and Environment" contained questions on the levels of knowledge about different energy options and general attitudes towards environmental and energy issues in the UK;
- Part B: "Energy Options" contained a choice experiment section containing 5 choice cards where respondents were asked to choose between four energy options: wind, biomass, nuclear and the current energy mix, depending on which mix of attributes they prefer. This section explained the UK Government's aim to reduce carbon emissions by 2020 and to generate 20% of the UK's electricity from low-carbon energy sources. Participants were given a short description of each of the energy options (Wind, Biomass, Nuclear and the Current Energy Mix) as well as being supplied with a picture for each of the power plant technologies (see Figure 2).

Figure 2:



After completing the choice cards respondents were asked to answer some follow up questions testing the reasons behind the choices they made and also some additional questions aimed at finding out more about public attitudes towards off-shore and micro-generation. This was done to test public attitudes towards alternative generation and provide a platform for further research.

- Part C: "Respondents / Household Profile" a final section containing socio-economic questions about respondents' age, education, work status, number of children and income. In this section respondents were reminded that the survey was strictly confidential, voluntary and information provided would only be used for statistical purposes.

4.2 Levels and attributes

Each of the power generating options in the experiment was described in terms of the following attributes: distance from respondent's home (distance), carbon emissions reduction (carbon emissions), local biodiversity impacts (biodiversity), land requirements (fixed attribute) and an annual electricity bill increase (cost attribute).

- *Distance from respondents' home* – is the distance from the respondent's home to newly built generation sites.
- *Carbon Emissions Reduction* - is the reduction in emissions that future energy options can provide in relation to 20% of the UK's electricity generation.
- *Local biodiversity* – the impacts on local number of species of birds, mammals, insects or plants.
- *Total land* – is the amount of land occupied by the energy option all over the UK in order to produce 20% of total UK's electricity.
- Annual Increase in Electricity Bill – the amount by which each household's annual energy bill will increase.

Table 2: Attributes, corresponding variables, levels and coding

Attribute's name	Variable Name	Description	Levels	Coding
Distance from respondents' home	Distance	How far/close the energy option will be located from your home.	0.25 miles, 1 mile, 6 miles, 10 miles	0.25, 1, 6, 10
Local Biodiversity	Biodiversity - more	Impact of the local biodiversity of species in the area surrounding the energy option	Wind: no change, less	1 - if more, 0 -
	Biodiversity - no change		Biomass: more, less	1 - if no change, 0 - all others
	Biodiversity - less		Nuclear: no change less	1- if less, 0 - all others
Carbon Emssions Reduction	Emissions reductions	Reduction in carbon emissions that relates to the 20% electrcity generation.	Wind: 99%, 97%	99, 97
			Biomass: 90%, 50%	90, 50
			Nuclear: 99%, 95%	99, 95
Total Land	Land	How much land the energy option will have to occupy all ove the UK in order to generate 20% of total electricity by	Wind: 5,832 ha	5,832
			Biomass: 816,000 ha	816,000
			Nuclear: 568 ha	568
Annual Increase in Electrcity Bill	Cost	How much your electricity will increase every year.	£20, £40, £67, £90, £143	20, 40, 67, 90, 143
Alternative specific constant for wind	Asc wind	Constant associated with the 'label' for wind power.	1 for alternative wind, 0 for all other alternatives	
Alternative specific constant for biomass	Asc biomass	Constant associated with the 'label' for biomass power.	1 for alternative biomass, 0 for all other alternatives	
Alternative specific constant for nuclear	Asc nuclear	Constant associated with the 'label' for nuclear power.	1 for alternative nuclear, 0 for all other alternatives	

Table 3: Example choice card

EXAMPLE Card

Characteristics	**Option 1 Electricity from WIND**	**Option 2 Electricity from BIOMASS**	**Option 3 Electricity from NUCLEAR**	**Option 4 Current Energy Mix**
Distance from home	6 miles *[10km]*	0.25 miles *[400m]*	1 mile *[1.6km]*	18 miles *[29km]*
Local biodiversity	Less	More	No change	Less
Carbon emissions *for producing 20% of UK electricity*	Reduction by 99%	Reduction by 50%	Reduction by 95%	Reduction by 0%
Total land *for producing 20% of UK electricity*	5,832 ha *Or 7,930 football fields*	816,000 ha *Or 1,190,750 football fields*	568 ha *Or 772 football fields*	1,594 ha *Or 2,167 football fields*
Annual increase in electricity bill	**£143**	**£40**	**£67**	**£0**
Please tick your preferred option	☐	☑	☐	☐

Table 2 contains more detailed information on the attributes and its levels and coding.

4.3 Choice alternatives

As part of the choice experiment respondents were asked to choose between four energy-generating alternatives: electricity from wind, electricity from biomass, electricity from nuclear, electricity form current energy mix. The latter is the 'status quo' option against which the other alternatives were measured. All alternatives that participants were presented with were labelled.

The experimental design of the choice experiment was developed using SPSS 14.0 and followed was a fractional factorial main effects design. Thirty-two choice profiles for each alternative were produced in the design. Thirty choice cards were generated randomly and the cards were blocked into six blocks of five choice cards. To minimise ordering bias, the order of the attributes between blocks was alternated (Fimereli et al, 2008). In summary each respondent was presented with a questionnaire survey containing five choice cards. Each card had four energy generating options described in terms of five attributes. They were asked to choose only one preferred option. An example of a choice card is presented below.

4.4 Sample selection and questionnaire logistics

There are different ways of carrying out public surveys such as postal, internet based, and face-to-face interviews. Each of these methods has its drawbacks and advantages. Face-to-face interviews tend to generate high response rates and tend to be more flexible in its implementation, but they are relatively expensive. Postal surveys tend to be cheaper, allow respondents to complete questionnaires at their own pace and are more easily elicit answers to sensitive questions, but they are often criticised for a high chance of a 'self-selection bias' and low response rates (Bennett and Blamey, 2001, McFadden et al. 2005). Internet-based surveys tend to also be cheaper and can potentially generate high response rates, but they are also subject to a self-selection bias and technical limitations for their development still exist. The current study was administered through a postal survey. This method was predominantly chosen due to its relative cost-efficiency given the scale of the surveyed area.

We have identified areas within Scotland that are representative of most of the country, namely Glasgow, Stirling, Fort William, Perth, Dumfries, Oban, Inverness, Aberdeen, Edinburgh, Isle of Lewis, Isle of Harris and Orkney (these included surrounding rural areas in each case). They were later combined into three distinct groups: 'South', 'Central' and 'Highlands and Islands' according to their geographical characteristics and population density. The number of respondents the survey was sent out to was scaled according to population size within each area. The survey was sent out to a sample of 1000 households across Scotland. Participants were chosen randomly based on the 2008 Electoral Register Database. Three weeks later a reminder containing another copy of a questionnaire was sent out to all non-respondents. After accounting for returned/undelivered questionnaires, 245 usable or partially usable responses were received – a total response rate of 27%, which is considered to be within the common range for mail surveys (e.g. Bateman et al., 2002).

Results

5.1 Sample characteristics

With 46% male, average annual income of £25,000 and 47 years average age, our sample provides a fairly good representation of a typical Scottish householder according to the Scottish Household Survey 2007/08. For more details on the comparison see Table 4 below.

We have also estimated the level of information that our sample had access to and their level of knowledge of low-carbon energy options offered in the current study, i.e. wind, nuclear and biomass. The vast majority of people in our sample had heard of wind power and nuclear power (96% and 88% respectively). Respondents, however, displayed much lower familiarity with biomass technology.

With respect to the type of information that the sample had access to from mass media sources, half of the sample stated to have access to mostly positive information about wind power, whereas 68% of respondents on the contrary stated to have mostly heard negative information about nuclear (see Table 5 for more details).

This perhaps is not surprising given the current Scottish Government's commitment to "no nuclear" in Scotland. At the same time the Scottish Government is backing renewables, such as wind power, which is of course reflected by the mass media coverage and as such the "type of information" that the public has access to.

To gain an insight into the general perceptions of the respondents towards key problems addressed in the study such as climate change and the UK's role in tackling this issue we also asked the respondents to express their views on some of the general statements described in Table 6.

We found that the vast majority of respondents agree that solving environmental problems should be a priority when it comes to public spending in the UK. Most of the respondents also agreed that climate change is a problem that needs to be addressed internationally and that everyone should substantially change our behaviour to tackle it. Public views were not as straightforward, however, with regards to investment in renewable and nuclear energy as a way of tackling climate change. As such only slightly over half of the sample (59% and 56% respectively) agree or strongly agree that the UK should invest more in these technologies.

Table 5: Knowledge of and access to information about discussed energy options

Knowledge of energy options	Wind	biomass	nuclear
% of People that heard about	96%	53%	88%
% of People that stated to have at least some knowledge about	85%	31%	36%
% of People that had access to mostly POSITIVE information about	50%	22%	11%
% of People that had access to mostly NEGATIVE information about	19%	17%	68%

Table 6: Public attitudes towards general statements regarding climate change

% of Total sample	Disagree or Strongly disagree	Unsure	Agree or Strongly agree
Solving environmental problems should be one of the top 3 priorities for public spending in the uk.	16%	11%	70%
Environmental problems such as climate change and air pollution have been exaggerated.	49%	24%	25%
Developed countries are the main contributors to global warming.	20%	15%	62%
The UK should invest more in renewable energy as a way to tackle climate change.	16%	21%	59%
The UK should invest more in nuclear power stations as a way to tackle climate change.	20%	20%	56%
Climate Change is a global problem that needs to be addressed internationally y all countries.	7%	3%	86%
We all have to substantially change our behaviour in order to help tackle climate change.	9%	8%	81%

Note: Based on total respondents, non response to these accounts for difference from 100%

5.2 Results of the choice experiment

This section of the paper reports our findings on two separate estimations. Firstly, we report on attitudes and preferences for the total Scottish sample including preferences according to socio-economic groupings and respondents' willingness to pay for the energy options given the different levels of attributes. Secondly we investigate divergence in preferences between three areas of Scotland (Highlands and Islands; Central; and South).

Random parameters Logit Model

As was mentioned earlier in section 3, one of the key requirements of the conditional logit model is the validity of the IIA assumption. This assumption was tested using Hausman and McFadden chi-square test (1984) and we found that the IIA assumption is rejected. To overcome this we then tested alternative model specifications that can relax the IIA property. The specifications tested were Random Parameters Logit Model (RPL), Nested Logit and Error Component Model . We found that the RPL model, which allowed the investigation of heterogeneity across respondents, also provided us with the best fit and therefore the remainder of the paper will focus on the results estimated using RPL specification.

As with the conditional logit model, in RPL models utility is decomposed into a deterministic part (V) and an error component stochastic term (e). Indirect utility is a function of the choice attributes (Zj), with parameters β, which may vary across individuals by a random parameter ηi, and of the socio-economic and attitudinal characteristics (Si) (Birol et al. 2006).

$$U_{ij} = V(Z_j(\beta + \eta_i), S_i) + e(Z_j, S_i)$$

Table 7: Random parameter logit estimation results

Variable	Comment	Original RPL Model including Socio-Economic Characteristics	
		Mean effect	t-statistic
Random parameters in utility functions			
Distance	*Distance Attribute*	0.035**	2.61
Biodiversity-no change	*No change in biodiversity*	-0.07	-0.7
Biodiversity - more	*Increase in biodiversity*	0.44**	2
Emissions reductions	*Reduction in carbon emissions*	0.01**	2.19
Non-random parameters in utility functions			
Asc Wind	*Alternative specific constants - Wind, Biomass and Nuclear*	2.48***	2.94
Asc Biomass		1.42	1.63
Asc Nuclear		1.92**	2.29
Cost	*Cost attribute (increase in electricity bill)*	-0.01***	-7.12
Sex*Asc wind	*Gender*	-0.66**	-2.16
Sex*Asc biomass		-0.49	-1.52
Sex*Asc nuclear		0.04	0.14
Kids*Asc wind	*Households with children*	0.6***	2.65
Kids*Asc biomass		0.49**	2.13
Kids*Asc nuclear		0.22	0.95
Age*Asc wind	*Age*	-0.45***	-4.47
Age*Asc biomass		-0.32***	-3.16
Age*Asc nuclear		-0.17*	-1.68
BNW*Asc wind	*We should all change our behaviour to tackle climate change*	-0.03	-0.43
BNB*Asc biomass		-0.09	-1.12
BNN*Asc nuclear		-0.29***	-3.65
More nuclear*asc wind	*The UK should invest more in nuclear power stations as a way to tackle climate change*	0.68**	2.03
More nuclear*asc biomass		0.16	0.45
More nuclear*asc nuclear		1.6***	4.49
ENW*Asc wind	*Solving environmental problems should not be one of the top 3 priorities for public spending in the UK*	0.51***	3.4
ENB*Asc biomass		0.44***	2.94
ENN*Asc nuclear		0.48***	3.2
Derived standard deviations of parameter distributions			
Distance		0.08**	2.44
Biodiversity-no change		0.13	0.28
Biodiversity - more		0.23	0.29
Emissions reductions		0.02**	2.38
Number of observations	1162		
Log likelihood value	-1245.6		

Note: ***, **, * = Significance at 1%, 5%, 10% level.

Table 8: Willingness to Pay (WTP) Estimates

Variable	Mean Effect	95% confidence intervals	t-statistic
Distance (per mile)	£3.8**	0.89 - 6.65	2.57
Biodiversity-no change (from baseline 'less')	-£7.69	-29.59 – 14.21	-0.69
Biodiversity – more (from baseline 'less')	£47.51*	-1.82 – 96.83	1.89
Emissions reductions (for % reduction)	£1.13**	0.87 – 2.17	2.12

Note: ***, **, * = Significance at 1%, 5%, 10% level.

To account for unobserved heterogeneity, and by specifying the distributions of the error terms e and η, the equation above can be expressed as:

$$P_{ij} = \frac{\exp(V(Z_j(\beta+\eta_i), S_i))}{\sum_{h\in C}\exp(V(Z_h(\beta+\eta_i), S_i))}$$

This model is not restricted by the IIA assumption hence the correlation of the stochastic part of utility is allowed between the alternatives via the influence of η (Birol et al. 2006).

In our study the RPL model with a non-random cost attribute was employed. The model was estimated using NLOGIT 4.0.4. All random parameters were assigned normal distributions, although triangular distributions were also considered. Distribution simulations were based on 500 draws using Halton's method.

5.2.1 Total Scottish sample

Table 7 reports the results for the Random Parameters Logit model (RPL) with added socio-economic variables, such as age, gender and number of children in the household. The other socio-economic variables were also tested but, since we found no significant impact of those variables, they were excluded from the final model. We also found that certain attitudinal variables had a significant impact on model fit, they are reported below.

For the overall Scottish sample our results suggest that people consistently identify distance, an increase in biodiversity and a reduction in emissions as the most significant attributes. These variables come through as significant at the 5% level and have positive preference associated with them. Standard deviations for distance and reduction in emissions attributes come through as significant at the 5% level, which suggests the presence of heterogeneity in the parameter estimates over the sampled population (Hensher et al., 2005). As expected, people prefer to live further away from power stations, wish to see an increase in biodiversity and have positive preferences towards a reduction in carbon emissions. At the same time they have strong negative preferences towards increases in their annual energy bill, as confirmed by the reported results (the cost attribute is negative and significant at the 1% level).

Interesting results were observed with regards to public attitudes towards alternative specific constants, i.e. respondents in the total sample displayed positive attitudes not only towards wind, but also towards the nuclear energy option compared to the current generation mix (alternative specific constants are positive and significant at 1% and 5% levels respectively). These results may have direct policy implications for Scotland given that the current Scottish Government made it clear that it will not support any new-build nuclear power stations in Scotland. The existing policy in itself may be one possible explanation of such positive preference, i.e. the public "knows" that new nuclear will be built outwith Scotland, hence the positive Scottish attitude towards it (a continuation of the positive willingness to pay for greater distance to a power station). On the other hand this preference may simply be a reflection of the fact that people do indeed prefer to have carbon free nuclear power plants and wind farms over existing coal and gas power stations.

Our analysis of socio-economic characteristics showed that females are more likely to choose the wind energy option, whilst positive preferences towards low-carbon energy (wind, biomass and nuclear) over the current generation mix are decreasing with age. Presence of children in the household is also a significant factor when it comes to choosing low-carbon energy options, specifically biomass and wind over the status quo.

A number of attitudinal variables did have an impact on model fit, as such they were included in the model. More specifically, those respondents who agree with the statement that "We should all significantly change our behaviour in order to tackle climate change" are less likely to choose the nuclear energy option over the current generation mix (negative and significant at 1% level). Perhaps not surprisingly those who agree that "The UK

Table 9: RPL model results of the regional analysis

Variable	Central Perth, Stirling and Aberdeen		South Glasgow, Edinburgh and Dumfries		Highlands and Islands Harris, Lewis, Orkney, Inverness, Fort William, Oban	
	Mean effect	t-statistic	Mean effect	t-statistic	Mean effect	t-statistic
Random parameters in utility functions						
Distance	0.04	1.64	0.07***	2.95	0	0.13
Biodiversity - no change	-0.19	-1.1	0.17	1.01	-0.06	-0.45
Biodiversity – more	0.24	0.34	0	-0.01	0.72**	2.16
Emissions reductions	0.01	1.54	0.02**	2.21	0	-0.11
Non-random parameters in utility functions						
Asc Wind	2.51*	1.76	1.37	1.53	2.51***	3.45
Asc Biomass	1.39	1.03	0.42	0.51	0.6	0.87
Asc Nuclear	2.18	1.56	0.6	0.69	1.74**	2.47
Cost	-0.01***	-3.45	-0.01***	-5.17	-0.01***	-3.52
Derived standard deviations of parameter distributions						
Distance	0.11	1.3	0.07	1.54	0.05	0.99
Biodiversity - no change	0.14	0.18	0.21	0.35	0.08	0.18
Biodiversity – more	0.71	0.41	0.3	0.35	0.21	0.25
Emissions reductions	0.01	0.54	0	0.27	0.01	0.51
Number of Observations		347		355		475
Log Likelihood Value		-413.9		-419.15		-550.73

Note: ***, **, * = Significance at 1%, 5%, 10% level.

should invest more in nuclear power stations to tackle climate change" displayed strong positive preference towards nuclear and wind energy options (positive and significant 1% and 5% respectively). Finally we found that those respondents who think that "Solving Environmental Problems should not be one of the top 3 priorities for public spending in the UK" over the status quo, i.e. respondents are willing to pay for low-carbon energy themselves rather than relying on public funds. This provides additional ground for further research when it comes to the investigation of public preferences towards existing energy policy in Scotland.

Implicit prices or marginal 'willingness to pay' (WTP) amounts associated with the CE attributes are reported in the Table 8. These reflect the value that respondents place on the change in a given attribute.

According to the results, the sampled population in Scotland is willing to pay on average £3.8 per mile for living further away from a power generating option. With regards to increase in biodiversity respondents are willing to pay £47.51 for an increase and £1.13 for a 1% reduction in carbon emissions. It is important to note that the values should not be interpreted as a 'precise' monetary figure, but an indication of the magnitude of respondents' willingness to pay. Taking the above into account implicit prices can serve as a valuable policy-making and investment analysis tool.

5.2.2 Regional analysis

Whilst realising limitations with the number of observations in our sample, at the next stage of the analysis we wanted to test whether energy preferences across Scotland were uniform throughout the country, or if there is any divergence depending on regional location. As discussed earlier in section 4.4, we have split our sample into three areas combining all the investigated regions: South, Central and Highlands and Islands according to their geographical characteristics and population density. Just as before the RPL model was used in the estimation, although we have not reported parameter estimates for any socio-economic variables, as we did not find them to be significant for the current section of the study. Regional analysis results are reported in Tables 9 and 10.

Due to the small size of the sample, our results are somewhat lacking statistical significance, but what they do indicate is that depending on the region of Scotland people place different values on different attributes of the study, for example people in the Highlands and Island seem to be

Table 10: Willingness to pay (WTP) estimates - regional analysis

Variable	**Central –** Mean effect	95% conf. interv.	t-stat	**South –** Mean effect	95% conf. interv.	t-stat	**Highlands and Islands –** Mean effect	95% conf. interv.	t-stat
Distance (per mile)	4.64*	-0.73 – 10.01	1.69	5.83***	1.7 – 9.96	2.77	£0.35	-5.16 – 5.86	0.13
Biodiversity-no change (from baseline 'less')	-£20.88	-58.7 – 16.97	-1.08	£15.00	-14.15 – 44.14	1.01	-£9.96	-54.5 – 34.63	-0.44
Biodiversity – more (from baseline 'less')	£26.54	-132.1 – 185.17	0.33	-£0.27	-67.83 – 67.3	-0.01	113.41*	-9.6 – 236.4	1.81
Emissions reductions (for % reduction)	£1.41	-0.35 – 3.17	1.58	1.51**	0.06 – 2.94	2.05	-0.09	-1.81 – 1.63	-0.11

Note: ***, **, * = Significance at 1%, 5%, 10% level.

more consistent in identifying increased biodiversity as the most valued attribute, whereas distance from respondents home comes through as significant for people in the Central region. For the respondents in the 'South' the attributes distance and reduction in emissions come through as highly significant (at 1% and 5% levels respectively). Given that Glasgow and Edinburgh, the two largest and highly populated cities in Scotland, are included in this group, such preference towards these two particular attributes seems logical. That is the population of these cities are likely to experience the highest background levels of air pollution in Scotland and are the most densely populated so proximity to electricity producing plants will be most strongly felt. This is especially true of Edinburgh, with two major coal power plants, Longannet and Cockenzie, located nearby.

Given the above, our results indicate that there is a great need for further research in this area since if confirmed our results will suggest that Scottish energy policy needs to be planned taking account of regional preferences to a much greater extent than is currently done.

5.2.3 Non-compensatory preferences

One aspect of the analysis that is of a particular interest is observed non-compensatory preferences across respondents. The fundamental assumption in random utility models since Lancaster (1966) and McFadden (1974) is that 'individuals' decisions respond to compensatory heuristics by which individual attributes are weighed by their contribution to the overall utility in order to evaluate the relative utility of each profile' (Arana, 2009). This implies that individuals are able to make trade-offs between attributes to identify the most preferred alternative. Previous research, conducted by authors such as Kahneman and Frederick, 2002; Gowda and Fox, 2002; Payne et al., 1993), showed that people often avoid making trade-offs and that such non-compensating behaviour can also be a fully rational process (Payne et al., 1990) (for more details see Arana, 2009). Presence of such non-compensatory behaviour, however, may have direct implications on the way the results of CE are interpreted and therefore, policy decision-making associated with them.

We found that a surprisingly large proportion (42%) of sampled respondents in our study consistently chose one energy option over the others. Out of those 46% of people chose wind in all cases, 4% chose biomass, 30% chose nuclear and 20% chose the current generation mix. Although consistent with random utility theory, such behaviour presents a challenge to a researcher in identifying rationality behind these choices. To test whether this behaviour affects the results of the original RPL model, we estimated a new model using RPL where all respondents that consistently chose one option over the others (e.g. wind energy option in all cases), were excluded from the analysis (see Table 11 for the results).

When comparing the results of the restricted sample with the original model, we found that the results were reasonably stable with regards to the alternative model specification. All of the signs remained unchanged and most of the attributes kept their level of significance with the exception of an increase in biodiversity, which appeared to be insignificant in the restricted model. As for alternative specific constants on the other hand, all of them, including the constant for biomass, came through as highly significant. Some changes were also observed in socio-economic variables, for example unlike in the original model, households with children as well as gender of respondents did not appear to have any significant impact on the respondents choices. With regards to implicit prices, however, values were relatively constant, except for the willingness to pay for an increase in biodiversity, which

Table 11: Results excluding respondents with "non-compensatory preferences"

Variable	Comment	Restricted Sample accounting for Non-compensatory Preferences	
		Mean effect	t-statistic
Random Parameters in Utility Functions			
Distance	Distance Attribute	0.09***	3.36
Biodiversity-no change	No change in biodiversity	0.01	0.04
Biodiversity - more	Increase in biodiversity	0.31	0.71
Emissions reductions	Reduction in carbon emissions	0.01**	2.09
Non-Random Parameters in Utility Functions			
Asc Wind	Alternative specific constants - Wind, Biomass and Nuclear	5.66***	3.8
Asc Biomass		4.69***	3.07
Asc Nuclear		3.82***	2.62
Cost	Cost attribute (increase in electricity bill)	-0.01***	-6.47
Sex*Asc wind	Gender	-0.38	-0.93
Sex*Asc biomass		-0.23	-0.55
Sex*Asc nuclear		0.33	0.76
Children*Asc wind	Households with children	-0.15	-0.68
Children*Asc biomass		-0.23	-0.95
Children*Asc nuclear		-0.18	-0.75
Age*Asc wind	Age	-0.64***	-4
Age*Asc biomass		-0.50***	-3.24
Age*Asc nuclear		-0.34**	-2.13
	We should all change our behaviour to tackle climate change	-0.18*	-1.66
BNB*Asc biomass		-0.25**	-2.3
BNN*Asc nuclear		-0.35***	-3.06
More nuclear*asc wind	The UK should invest more in nuclear power stations to tackle climate change	1.50***	2.82
More nuclear*asc biomass		1.35***	2.62
More nuclear*asc nuclear		2.20***	3.9
ENW*Asc wind	Solving environmental problems should not be one of the top 3 priorities for public spending in the UK	0.54***	2.94
ENB*Asc biomass		0.59***	3.23
ENN*Asc nuclear		0.69***	3.6
Derived standard deviations of parameter distributions			
Distance		0.07**	1.96
Biodiversity-no change		0.37	0.69
Biodiversity - more		0.41	0.19
Emissions reductions		0.01*	1.75
Number of Observations			692
Log Likelihood Value			-750.43

Note: ***, **, * = Significance at 1%, 5%, 10% level.

Table 12: WTP estimates for the restricted sample accounting for non-compensatory preferences

Variable	Mean effect	95% confidence intervals	t-statistic
Distance (per mile)	£4.5***	2.39 – 7.6	3.76
Biodiversity-no change (from baseline 'less')	£0.43	-19.15 – 20.01	0.04
Biodiversity – more (from baseline 'less')	£22.56	-43.46 – 88.58	0.67
Emissions reductions (for % reduction)	£0.86**	0.04 – 1.68	2.05

Note: ***, **, * = Significance at 1%, 5%, 10% level.

came through as just insignificant. Although relatively robust, our results suggest that further investigation of the displayed non-compensatory preferences is needed to fully understand underlying reasons behind them including those at a regional level.

6. Conclusions and future research

The fundamental purpose of this study was to determine public preferences and willingness to pay for alternative energy options, such as wind, nuclear, biomass and current generation mix, all of which may form an integral part of Scotland's future generation portfolio. To achieve this we used a choice experiment approach involving a countrywide mail survey sent out to a random sample of 1000 households across Scotland. We compared public preferences across four energy options wind, biomass and nuclear relative to the current generation mix (the status quo option). These options were described in terms of the following attributes: distance from respondent's home, carbon emissions reduction, local biodiversity impacts, land requirements (fixed attribute) and an annual electricity bill increase (cost attribute).

Our results show that respondents in Scotland display strong positive preferences towards wind power over the current generation mix. In addition it was found that the nuclear energy option is also more attractive to the sampled population rather than the status quo. While the first finding is inline with current Scottish policy of heavily backing renewables, the positive attitudes towards nuclear suggest that the current "no nuclear" policy for Scotland should perhaps be further examined.

According to the results, respondents want to live further away from energy generating options and consistently identify an increase in biodiversity as an attribute, which is important to them. They also display positive willingness to pay for a reduction in carbon emissions.

A large number of studies (e.g. Clarkson, R. and K. Deyes, 2002, Fankhauser, S. (1994), Haraden, J. (1993), Stern, N.H. et al (2006)) have investigated reductions in carbon emissions and estimated the shadow price of carbon (for a meta-analysis of social cost of carbon listing over 40 studies see Tol R., 2008). The comparison of our values (for WTP for a 1% reduction in carbon emissions) with these studies, however, is difficult, as the values are typically reported in pounds per tonne of carbon (£/tC) or in pounds per tonne of CO2 equivalent (£/tCO2e). Indeed, the shadow price of carbon values recommended for use in economic appraisal in the UK (DEFRA, 2007) also estimate this figure as £/tCO2e. No studies reporting directly comparable results, for a 1% reduction in emissions, could be found in the literature. Despite these issues of comparability applying our average WTP of £1.3 for a 1% reduction in carbon emissions (using annual emissions from power generation) to all UK households gives an estimate of £15.1/tCO2e. Comparing this to the shadow price of carbon value as per DEFRA 2007 of 25 £/tCO2e, represent a surprisingly close match, especially when taking into account our 95% confidence intervals (12.5-93.6 £/tCO2e).

With regards to identification of regional preferences across Scotland, we found that depending on the location respondents identify different attributes as important to them. For example, those who live in the Highlands and Islands displayed consistent preferences towards an increase in biodiversity, indicating that this attribute is more important to them than distance and level of reduction in carbon emissions. On the contrary, respondents living in the Central and Southern regions (see section 5.2.2 for more details) identified distance and reduction in carbon emissions as the most important attributes. Although somewhat statistically limited, it is felt that these results may have direct implications on the development of Scottish energy and policy planning, especially when it comes to the placement of future power plants.

Another area that calls for further investigation is the presence of non-compensatory behaviour amongst the sampled population. It was found that almost half of the sample (42%) consistently chose one energy option above the others, independently of attribute levels. Although when tested our results proved to be fairly robust, i.e. when respondents who displayed "non-compensatory preferences" were excluded from the analysis, we found

little impact on the overall results (other than the significance of increasing biodiversity), the underlying reasons behind such behaviour are still to be understood.

In summary it is felt that our research will provide a fresh and important contribution to future decision-making in the area of energy policy. Scotland is faced with upcoming changes to the generation portfolio of the country and significant targets have been set for reductions in emissions from this sector of the economy. Decision-making has been based on relatively sparse information given the lack of literature aimed at the investigation of energy preferences for Scotland. Our research is suggestive of which technologies would be most acceptable to the Scottish public. It is also indicative that further investigation is required to identify where given technologies would be most preferred in Scotland, which in combination with generation potential may suggest an optimal future generation portfolio that will be politically palatable in achieving Scotland's world-leading emissions reduction targets.

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Endnotes

[1]The LCPD requires large electricity generators, and other large industrial facilities, to meet stringent air quality standards from 1 January 2008. If generators opt-out of this obligation, the plant will have to close by the end of 2015 or after 20,000 hours of operation from 1 January 2008, whichever is the sooner. According to BERR, approximately 12 GW of coal and oil-fired generating plants have opted-out and will have to close by the end of 2015, representing about 15% of Great Britain's present total capacity. Energy Industry Markets Forecast 2008-2015, Scottish Enterprise.

The electricity generation mix in Scotland: the long and windy road?*

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1. Introduction

The mix of technologies used to generate electricity in Scotland has evolved over the last ninety years. Since 2000, there has been a rapid increase in renewables capacity and generation, particularly in onshore wind. This has been supported by UK and Scottish policy and the associated funding mechanisms, including the Renewable Obligations Certificates (ROCs). In the coming decade, the Scottish generation mix is likely to see unprecedented changes that will include significant investments in a range of new generation technologies.

Section 2 of this paper explains how the existing Scottish electricity generation mix was attained and Section 3 identifies the key drivers of changes over the next decade. Section 4 briefly examines some published scenarios for the Scottish generation mix and sets these in the context of the (recently updated) Scottish Government's targets for electricity generation. The scenarios are informed by recent technology-specific "roadmaps". Section 5 concludes by discussing the implications for policy.

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2. Development of the existing electricity generation mix in Scotland

Tables 1 and 2 show how the present operational electricity generation capacity in Scotland has developed through time. In Table 1, reading along the row for an individual technology identifies the decades in which the capacity (in MW) that is operational today was installed. Reading down a particular column in this table shows how much of the total present Scottish electricity generation capacity was installed in that decade. Similarly, each cell in Table 2 shows the number of separate facilities commissioned, by technology and decade. These two tables identify the evolution of the current Scottish electricity generation mix.

Table 1 shows the major periods of activity in terms of the existing generation mix in Scotland. Almost one-third of the present-day installed capacity was commissioned in the 1970s, with over 75% installed between the 1960s and 1980s. The 1990s saw only a fraction of the investment of earlier decades, with 65MW of new capacity commissioned, 63MW of which came from wind generation commissioned between 1995 and 1999. Table 1 reveals that of the 2,007MW of capacity commissioned since 2000, over 90% has come from renewable technologies, with most coming from onshore wind projects. During this period, 1,685MW of onshore wind capacity and 39 onshore wind projects have been installed.

At present, investment in renewables generation capacity is progressing more rapidly than the period immediately following the Second World War. That period saw the formation of the North Scotland Electricity Board and the generation of electricity from the water of the glens of Scotland using hydroelectric technologies (Hannah, 1982). These investments in the 1950s led to 791MW of capacity installed across 38 projects. Each of these individual hydro projects were part of larger schemes, such as the 262MW Sloy installation. The Sloy scheme comprised ten separate facilities with individual facilities coming into operation at different times between 1950 and 1963. The Great Glen scheme was similar in nature, with a total capacity of 225MW. The earliest of its constituent parts dates from 1955 and the most recent, an addition of 100MW to this scheme, from 2008.

Tables 1 and 2 also identify the development of major capacity in non-renewable facilities: the coal stations at Longannet and Cockenzie in the 1960s and 1970s, the gas station at Peterhead in the 1980s, and the nuclear facilities in the 1970s and 1980s. However, since 1990, almost 94% of the new capacity has been in renewable technologies, with much of this occurring since the year 2000.

Rather than the installed capacity for each technology, Table 3 gives the electricity (in GWh) generated by different technologies in 2009 (the most recent year for which data are available) and their respective share of total Scottish

Table 1: Capacity (in MW) of plants operational in Scotland in May 2010, by technology and decade of commission or initial generation

		1920s	1930s	1940s	1950s	1960s	1970s	1980s	1990s	2000s	Total
Non-renewables	Coal	-	-	-	-	1,152	2,304	-	-	-	3,456
	Nuclear	-	-	-	-	-	860	1,205	-	-	2,065
	Gas/Oil	-	-	-	-	-	-	1,180	-	-	1,180
	Diesel	-	-	9	105	-	10	-	2	3	129
	Gas	-	-	-	-	-	-	-	-	123	123
Total non-renewable		-	-	9	105	1,152	3,174	2,385	2	126	6,953
Renewables	Wind (onshore)	-	-	-	-	-	-	-	63	1,685	1,748
	Hydro	17	186	-	791	173	-	2	-	130	1,299
	Pumped storage	-	-	-	-	440	300	-	-	-	740
	Biomass	-	-	-	-	-	-	-	-	44	44
	Poultry litter	-	-	-	-	-	-	-	-	12	12
	Wind (offshore)	-	-	-	-	-	-	-	-	10	10
Total renewables		17	186	-	791	613	300	2	63	1,881	3,853
	Total	17	186	9	896	1,765	3,474	2,387	65	2,007	10,806

Source: DECC, Digest of United Kingdom Energy Statistics, accessed September 2010

Table 2: Number of plants operational in Scotland in May 2010, by technology and decade of commission or initial generation

		1920s	1930s	1940s	1950s	1960s	1970s	1980s	1990s	2000s	Total
Non-renewables	Coal	-	-	-	-	1	1	-	-	-	2
	Nuclear	-	-	-	-	-	1	1	-	-	2
	Gas/Oil	-	-	-	-	-	-	1	-	-	1
	Diesel	-	-	2	3	-	1	-	1	1	8
	Gas	-	-	-	-	-	-	-	-	1	1
Renewables	Wind (onshore)	-	-	-	-	-	-	-	4	39	43
	Hydro	2	7	-	38	14	-	1	-	11	73
	Pumped storage	-	-	-	-	1	1	-	-	-	2
	Biomass	-	-	-	-	-	-	-	-	1	1
	Poultry litter	-	-	-	-	-	-	-	-	1	1
	Wind (offshore)	-	-	-	-	-	-	-	-	1	1
	Total	2	7	2	41	16	4	3	5	55	135

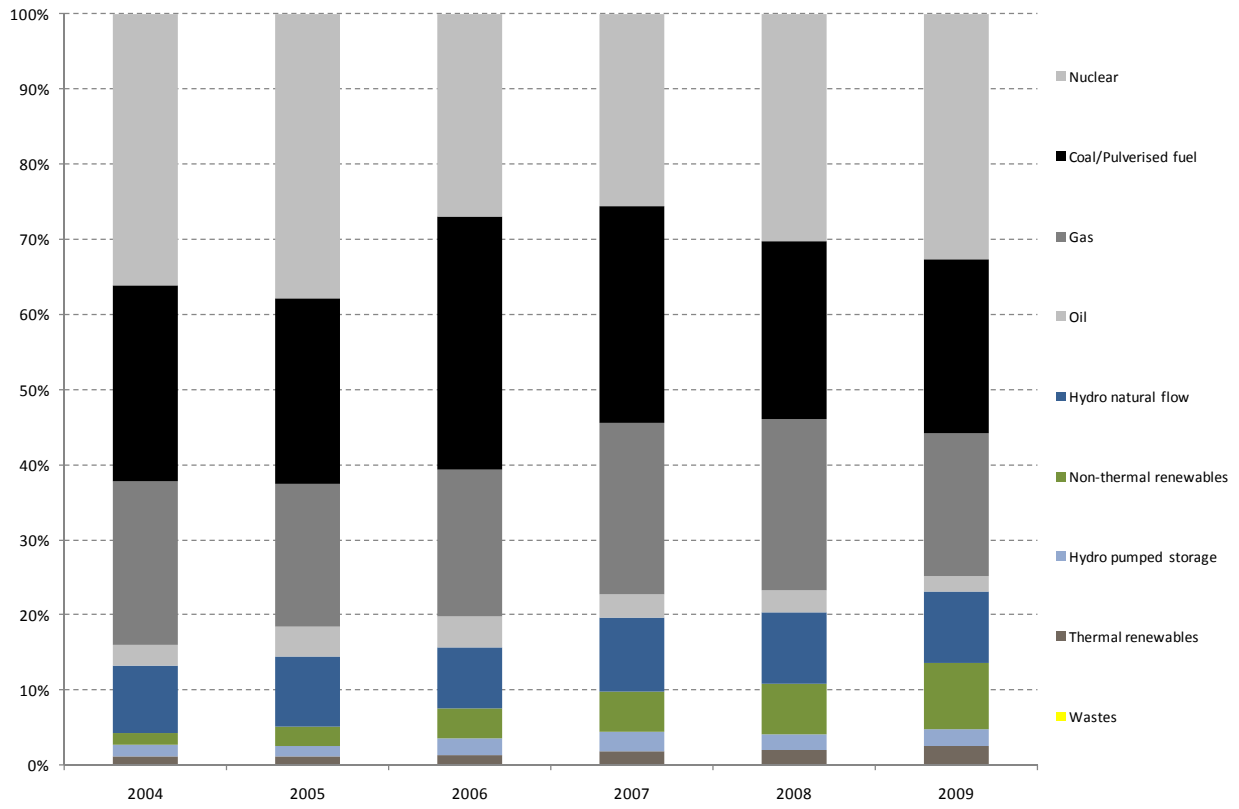
Source: DECC, Digest of United Kingdom Energy Statistics, accessed September 2010

Table 3: Generation in Scotland in 2009 by technology, GWh

	GWh	% share
Total from non-renewables	39,476	76.9
Nuclear	16,732	32.6
Coal / Pulverised fuel	11,965	23.3
Gas	9,690	18.9
Oil	1,089	2.1
Total from renewables	11,850	23.1
Hydro natural flow	4,877	9.5
Non-thermal renewables	4,558	8.9
Hydro pumped storage	1,087	2.1
Thermal renewables	1,310	2.6
Wastes	18	0.0
Total from renewables eligible under RO	8,185	15.9
Total, GWh	51,325	100.0

Source: DECC Energy Trends, December 2010. Note: Totals may not sum due to rounding.

Figure 1: Recent electricity generation in Scotland by technology, 2004-2008, % share of total generation



Source: DECC Energy Trends, various issues.

electricity generation in Scotland. Total generation was 51,325 GWh. Approximately 23% comes from renewable technologies. Note that this is significantly lower than renewables share of installed capacity in Scotland due to the lower capacity factors of these technologies. Nuclear contributes the largest share (over 30%) and coal (23%) and gas (19%) produced significant shares. Figure 1 shows, for the same technologies identified in Table 3, how the contribution of each technology to total electricity generation in Scotland has changed between 2004 and 2009.

Table 4 identifies where the electricity generated in each of the countries of the UK was actually consumed in 2009.

Table 4: Production and consumption of electricity by region of UK, 2009, GWh

		UK region of generation				ROE imports	
		England	**Scotland**	**Northern Ireland**	**Wales**		**Total consumption**
A	Generators own use	12578	3792	119	4828		21317
B	England	249051	10209		8287	3228	270775
C	Scotland		33010				33010
D	Northern Ireland		1937	6836			8773
E	Wales				17740		17740
F	ROE exports			367			367
G	Transmission losses	4838	584	156	315		5893
H	Distribution losses	17615	1793	548	1061		21017
A+B+C+D+E+F+G+H	Total generation	284082	51325	8026	32231	3228	378892

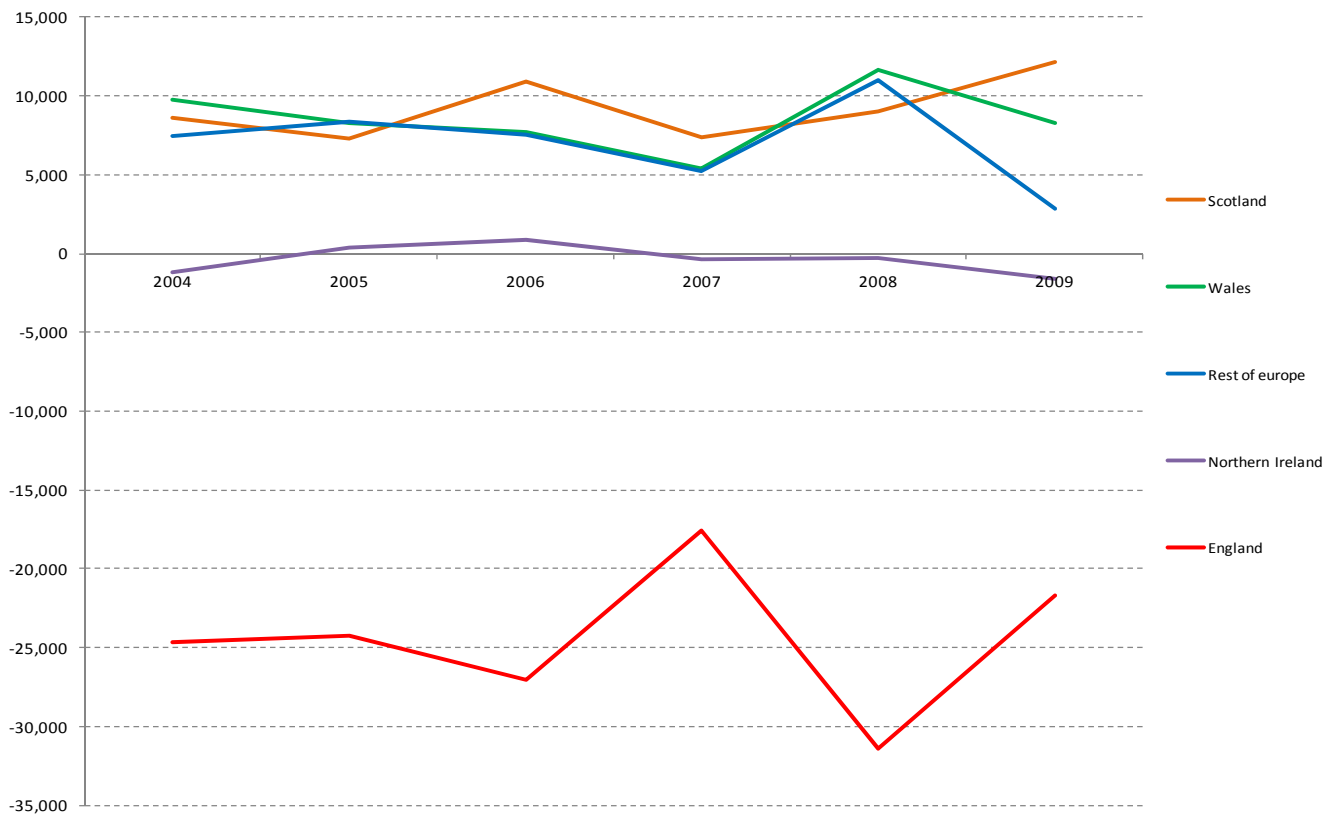
Source: DECC Energy Trends, December 2010, and authors calculations. Totals may not sum due to rounding.

Both Scotland and Wales were net exporters of electricity in this year, exporting 23.7% and 25.7% of net electricity generated in each region respectively. Northern Ireland was a net importer of electricity, with imports from Scotland greater than its exports to the rest of Europe. The 500MW Moyle interconnector between Scotland and Northern Ireland – which opened in 2002 – is currently a net exporting route for Scottish electricity. Scottish electricity generation also contributes to electricity consumed in England. Note that these figures refer to net exports over the year, and not half-hourly flows, where the regional pattern of generation and use could be quite different.

Reading along row B, for example, we see that of the 270,775GWh of electricity consumption in 2009 in England, just almost 92% was met by English generation with the rest coming from imports from Scotland (3.8%), Wales (3.1%) and the Rest of Europe (1.2%). For Northern Ireland, the pattern was quite different, with net exports to the rest of Europe corresponding to 4.6% of total generation, and net imports from Scotland making up 22.1% of total use.

Figure 2 shows how the regional trade in electricity has changed between 2004 and 2009. On the vertical axis is the difference between annual regional exports and imports of electricity to regions of the UK (in GWh). While Northern Ireland has small net imports and exports (in absolute terms) over the five years, we can see that significant net imports by England (equivalent to between 6.1% and 10.7% of annual electricity consumption in that region) are provided by exports from Scotland, Wales and the rest of Europe.

Figure 2: Net exports of electricity by region of UK, 2004 to 2009, GWh



Source: DECC Energy Trends, various years.

3. Factors affecting the future electricity generation mix in Scotland

Several interconnected factors are likely to produce significant changes in the future capacity and electricity generation mix in Scotland. These are due to two broad types of factors: technical and policy.

There are two key technical factors that are important influences on the way in which electricity is generated in Scotland. One is developments in the network and the grid. The second is the remaining lifetimes of existing plant. We attempt to summarise these issues here, beginning with the electricity transmission system. It has been acknowledged

that significant reinvestment will be necessary over the next twenty years if renewable energy sources, typically located in areas away from major centres of demand, are to meet the levels of envisioned penetration (Royal Society of Edinburgh, 2006; Forum for Renewable Energy Development in Scotland: Marine Energy Group, 2009). ENSG (2009) gives details of the types of grid investments required under alternative scenarios. It has been argued that substantial upgrades are needed to Scotland's electricity transmission system, and that this will depend on the level of renewable capacity. A recent estimate suggested that a programme of network investment in the (UK) transmission grid totalling £4.86 billion will be required (ENSG, 2009). Such grid enhancements include plans to increase the capacity of interconnection between Scotland and England through subsea HVDC cables to complement the existing onshore connection. Such transmission grid investments, however, require the permission of the networks regulator (OFGEM), which then allows the grid owner to recoup the costs of investment from generation customers who use the network, plus a (regulated) return on their investment. The regulator therefore predicts the extent to which network extensions would be used before it grants permission. But generators will not be willing to contract to site facilities in places served by the new grid until the new grid investment is made. This explains some of the delays in bringing forward additional generation in areas currently not served by the transmission network, and also emphasises the importance of developing an appropriate network for delivering the energy goals set by Scotland and the UK.

Concerning the lifetime of existing plants, the two major coal power stations in Scotland are now covered by the European Union Large Combustion Plant Directive. From 2011 they will have to stop production after 10,000 additional hours of operation, or at the end of December 2015, whichever is sooner. At the time of writing, Scottish Power – the operator of Cockenzie – is consulting on replacing the coal station with a Combined Cycle Gas Turbine (CCGT) station, together with the associated infrastructure. Coal stations may remain in Scotland in the long term with the use of Carbon Capture and Storage (CCS) technologies, such that the vast majority of their emissions are prevented from entering the atmosphere by being buried in previously depleted gas fields. Such storage capacity exists in the North Sea (Scottish Centre for Carbon Storage, 2009a) and it is hoped that CCS technologies might play a role in the future of coal generation in Scotland and the UK, although no full demonstration-scale plant has been completed. A prototype Carbon Capture unit is undergoing testing at Longannet coal power station. There are EU plans for 10-15 demonstration projects for CCS to be operational by 2015, although widespread deployment of CCS technologies is not expected to occur until 2020 (Scottish Centre for Carbon Storage, 2009b).

Table 5: Renewable energy developments in Scotland at stages prior to operation stage, as of 10th September 2010, MW

Technology	Under construction	Resolution to consent	In planning	In appeal	In scoping	SRO outstanding	Total
Hydroa	103.40	24.65	19.02	0.00	20.83	5.49	173.39
Onshore wind	431.05	2,832.18	3,593.28	811.60	2,610.31	4.31b	10,282.73
Offshore wind	0.00	0.00	0.00	0.00	115.00	4.31b	119.31
Energy from waste	2.73	21.30	4.27	0.00	5.80	40.46	74.56
Biomass electricity	13.70	98.80	39.00	0.00	566.00	12.90	730.40
Biomass heat	6.40	155.00	34.32	0.00	25.00	0.00	220.72
Wave	0.00	7.00	0.00	0.00	600.00	0.00	607.00
Tidal	1.00	0.00	10.00	0.00	632.00	0.00	643.00
Total	558.28	3,138.93	3,699.89	811.60	4,574.94	67.47	12,851.11

Notes: a = excludes pumped hydro, b = total wind capacity with SRO outstanding is 8.62MW, but no disaggregation by On- or Offshore are provided in source. We have split this between On- and Offshore wind 50:50. Source: Scottish Renewables (2010)

Of the current operational nuclear plants in Scotland Hunterston B was opened in 1976 and Torness in 1988. These plants are now reaching the end of their design lives, and are scheduled for closure in 2016 and 2023 respectively (RSE, 2006). In both cases, plant lifetime extensions are possible and would typically increase the working life of each plant by around 5 years. The recent report by a committee of members of the Scottish Parliament (2009) indicated that, while it did not see a new generation of nuclear facilities as necessary, "there will be a need to extend the operating lifetimes of the current generation of nuclear power stations in Scotland" (Scottish Parliament, 2009, paragraph 144). This is to avoid the perceived "energy gap" caused by the loss of existing coal and nuclear facilities.

As well as these environmental regulations, oil and gas generation will be affected significantly by the increasing level and volatility of fuel prices. Indeed, in the case of both forms of generation, the marginal cost of production will be a function of the prevailing fuel price (subject to any fuel contracts). For the period to 2020 and beyond, fuel prices are expected to rise (van Ruijven and van Vuuren, 2009). This reflects current concerns about resource depletion (e.g.

see de Almeida and Silva, 2009), reduced investment, greater demand (and uncertainty), and geopolitical risks. The range of fuel price forecasts is often huge and higher oil prices have been predicted before (for example, Saunders, 1984).

The main factors affecting the shape of energy policy in Scotland have been discussed elsewhere (Allan et al, 2008). Of course, EU and UK energy policies will continue to exert significant impacts on the Scottish generation mix. For example, the efficacy of the EU ETS in establishing a credible long-term carbon price is of crucial importance in correcting for the pollution externalities embodied in fossil fuel generation. We return to the role of the EU ETS in Section 5. Here we briefly summarise relevant aspects of Scottish (and UK) energy policies. Since devolution in 1999, electricity generation in Scotland has increasingly become a concern of the Scottish Government, despite energy being an issue that is reserved to Westminster. The Scottish Government has set ambitious targets for the share of Scottish electricity that comes from renewable sources. Its previous target was for 50% of gross electricity consumed in Scotland to come from renewable sources by 2020, with an interim target of 31% in 2011. During the writing of this paper, the Scottish Government announced that it would be increasing its 2020 target to 80%. It is not clear if any new interim targets will be set.

As of 2009 (the most recent year for which data are available) renewable electricity generated in Scotland was 23.1% of Scottish generation. It can be verified from Table 4 that for Scotland, total electricity generation less transfers equalled 39,179 GWh (i.e. total generation (the final row) less exports to England (row B) and Northern Ireland (row D)), while from Table 3, the amount of renewable generation in 2008 was 10,745 GWh (this is the sum of generation from “Hydro flow”, “Non-thermal renewables” and “Thermal renewables”). Renewable electricity generated in Scotland as a share of Scottish generation minus transfers was therefore 27.4% in 2009. We note that the existence of an electricity grid covering Great Britain (plus an interconnector between Scotland and Northern Ireland) means that there is no need for Scottish demand to be limited to Scottish generation. With regards to nuclear, the Scottish Government has stated that future applications for the building of new nuclear stations are likely to be rejected, a position backed in a vote in the Scottish Parliament[1]. Depending on circumstances, however, Scotland could be in a position of importing electricity from a GB grid which could have been produced in nuclear facilities in England (although the scenarios considered in the next section all envisage Scotland continuing to be a net electricity exporter up to 2020).

Renewable electricity in the UK (including Scotland) is supported through the Renewables Obligation (RO), which requires electricity supply companies to provide Renewables Obligations Certificates (ROCs) to the electricity regulator (OFGEM). The number of certificates that must be produced is currently equivalent to 4.27 ROCS per 100 MWh supplied in 2010/11), and the UK Government intends that the ROC support will remain until 2037. These certificates are earned by accredited generators for each MWh generated using renewable energy sources. They can be sold in the ROC market, with generators on the supply side, and electricity retail companies on the demand side. The price of ROCs in theory is restrained by the provision of an alternative method by which supply companies can meet their obligation, paying a buyout price, which began at £30 per MWh in 2001 and rises in line with the Retail Price Index every year. In 2009/10 the buyout price was £37.19.

Monies received by OFGEM from supply companies paying the buyout price for any ROCs they are unable to produce are redistributed back to electricity supply companies, whose share of the total redistributed buyout fund is in proportion to their contribution to the total number of ROCs received. In practice, this has meant that since inception the annual value of a ROC has been between 20% and 50% higher than the buyout price, producing an important stimulus to renewable energy development (as seen from the growth in renewable capacity between 2000 and 2009 in Tables 1 and 2).

From April 2009, the UK government introduced “banded” ROCs, whereby accredited renewable electricity generators receive different quantities of ROCs for each MWh they produce, depending on the technology used to generate each MWh. In this way, the support for renewables is no longer “technology-blind”, but is intended to bring forward developments in generation technologies other than onshore wind. The Scottish Government has introduced further differentiation, designed to favour new marine technologies. This began with the Marine Supply Obligation, which was superseded by the banded ROCs for wave and tidal stream in April 2009. Under the banded ROCs, each generator using wave technologies to generate electricity receives 5 ROCs per MWh, while tidal technologies receive 3 ROCs per MWh[2].

Along with ROC banding, other measures underline the Scottish Government’s support for marine technologies. These measures include the EMEC testing site on Orkney, the £13 million Wave and Tidal Energy Scheme[3] (WATES) funding for testing devices in Scottish waters, and the £10 million Saltire Prize challenge[4]. These initiatives underline the intention of Scottish Government to ensure that renewables development in the next ten years is not limited to as narrow a range of technologies (predominately onshore wind) as has been the case until now.

Table 5 identifies the capacity of renewable energy projects in Scotland, by technology, at pre-operational stage. This includes projects without planning permission, which are those indentified in the stages other than “Under construction” in Table 5. Even assuming that not all projects are granted permission, there is demand from generators to install renewable energy capacity in Scotland. Over 80% of

the capacity of the proposed projects relates to Onshore wind, which is likely to provide the bulk of new renewable energy developments up to 2020. Thus, existing renewable electricity generation plans suggest that a balanced portfolio of renewable technologies will not be delivered.

It is interesting to note that in the year since September 2009 the total capacity of pre-operational renewable energy developments increased by over 1,500MW. This is largely due to the increase in Biomass heat (up 149.16MW), Biomass electricity (up 172.2MW) and significant increases in the amount of Wave and Tidal capacity at the "Scoping" stage (up 600MW and 570MW respectively).

Previous work (Allan et al, 2010a) has identified the UK's recent Feed-in Tariff (FiT) scheme (DECC, 2010) as the "most significant recent policy initiative" in stimulating the penetration of distributed generation technologies. For installations under 5MW this measure replaces the Low Carbon Building Programme and the Renewable Obligation. Under this scheme, licensed electricity suppliers are required to pay a tariff to small scale low-carbon generators for electricity generation[5], and an additional export tariff when the electricity is exported to the grid. These tariffs apply for the operational lifetime of the device. By obliging electricity suppliers to purchase renewable electricity from suppliers at a favourable price, the FiTs policy provides emerging renewable technologies an opportunity to compete in the electricity market. The policy is intended to increase the uptake of small-scale low carbon technologies by increasing their attractiveness for households and communities.

The FiTs are scaled according to technology, and payments are scheduled to gradually fall over time, so as to produce incentives for cost-cutting and efficiency measures in renewable electricity industries. The idea behind gradual tariff reductions is that as demand for small-scale renewable devices grows, manufacturers can take advantage of economies of scale, price reductions are passed onto the consumer, and the industry becomes competitive on its own. In the UK, there are indications that FiTs are viewed as potentially profitable opportunities, with utility companies financing solar installations in housing developments and schools (Solar Power Portal, 2010), and the FiT scheme is likely to remain a future stimulant to investment in renewable energy devices by utilities and local authorities, as well as private investors.

4. Scenarios for Scotland's future electricity generating mix

4.1 Scenarios from 2008 and 2009

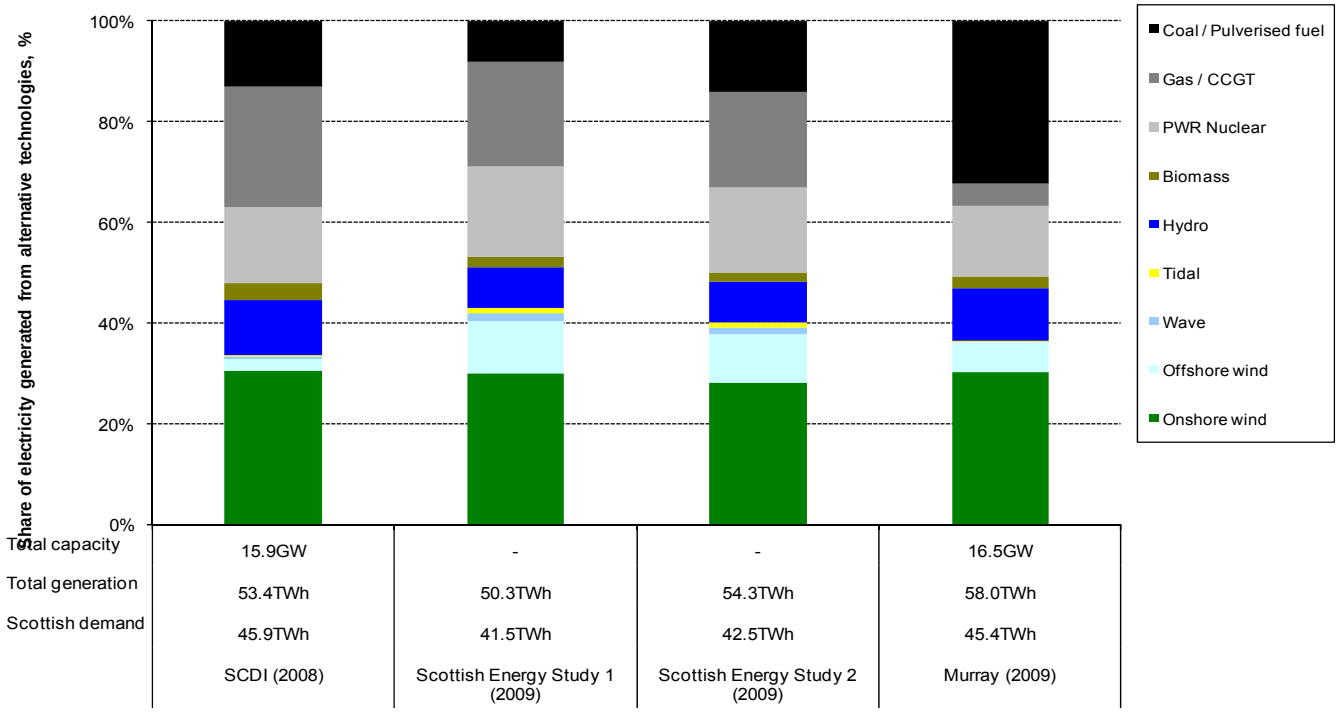
We study three projections from 2008/9 of the Scottish electricity generation mix for Scotland in 2020. Two of these are produced by the private sector (SCDI, 2008; Murray, 2009[6]), while the third comes primarily from a recent Scottish Government document "Scottish Energy Study" (AEA Technology, 2008). In this third study there are two alternative scenarios, configured on "Central" and "High" assumptions regarding the future of primary energy prices. In total therefore we have four scenarios. For ease of exposition, we label these four scenarios the following: SCDI, Murray, and SES1 and SES2, respectively.

All four scenarios focus on the same year, 2020, and have a number of other similarities. First, the total of Scottish electricity demands are broadly similar across all the scenarios. The SCDI scenario predicts annual increases between 2008 and 2014 of 0.9%, reduced to 0.4% per annum for 2016 to 2020. The Scottish consumption in this scenario for 2020 is 45.9TWh, 9% higher than demand in 2008. Murray follows the assumptions in SCDI. However having been published six months later, this report is able to reflect the experiences of early 2009 when economic output and energy consumption fell in Scotland. The Murray (2009) study therefore assumes no growth in electricity demand between 2008 and 2009, then the same pattern of demand growth as SCDI between 2009 and 2020. This gives total Scottish electricity demand in 2020 of 45.4TWh. Total demand for electricity (including losses and own use) in Scotland according to the SES1 scenario will be 41.5TWh, and 42.5TWh in the SES2 scenario. These are both actually slightly lower than demand in 2005 and are therefore around 9% lower than the other scenarios.

Second, given the significant uncertainty surrounding some of the anticipated developments discussed in Section 2, it is perhaps somewhat surprising that the installed capacity and total amount of electricity generated in Scotland in 2020 remains broadly the same across the four scenarios. The SCDI scenario predicts generation of 53.4TWh in 2020, coming from an installed capacity of 15.9GW. The Murray report predicts a slightly higher level of generation of 58.0TWh with a correspondingly higher installed capacity of 16.5GW. As with consumption, total generation is lower in both of the AEA Technology scenarios. The SES1 and SES2 scenarios, have total generation of 50.3TWh and 54.3TWh respectively. While there are no capacity figures given for the SES1 and SES2 scenarios, both see large increases in the extent to which renewable generation technologies provide electricity to the generation mix. There is also the continuation of some nuclear (at least through 2020), a move towards "clean coal" and the replacement of some new gas capacity. These figures suggest that the total capacity for generation in Scotland would be significantly higher than current levels, particularly given the lower capacity factors expected for onshore wind, which other commentators expect to produce much of the growth in renewables.

We can see from the projected levels of generation and demand in Scotland in 2020 that in all four scenarios Scotland is forecast to remain, as now, a large net exporter of electricity to the rest of the UK (i.e. its local consumption is significantly less than its local generation). However, each of the scenarios anticipates a different development path for generation technologies, which give us four alternative

Figure 3: Generation mixes in each of the four 2008/2009 scenarios



generation mixes for Scotland in 2020. These generation mixes are displayed in Figure 3.

Consider first the share from renewable technologies. In each of the scenarios there is a significant increase in generation from renewable sources for the reasons already discussed. The lowest renewable share in generation comes from the SCDI scenario with 48%, while the highest share comes from SES1 scenario is 53%. Within renewable technologies, Onshore wind provides most of the renewable generation (and around 30% of the total generation), a feature which is common across all scenarios, while Hydro provides around 10% of total generation. The remainder of renewable generation is assumed to come from a range of Biomass, Offshore wind and Wave and Tidal technologies. Offshore wind contributes, in all scenarios apart from SCDI (where biomass provides 3.4%), the third highest share of renewable generation.

It is in non-renewable technologies that the largest differences are seen across the scenarios. Whilst nuclear is expected to provide between 14% and 18% of total generation, the share of coal and gas in the total generation mix does differ more radically, particularly so in the GH scenario where the mix is heavily in favour of coal generation, rather than gas, while in the other scenarios the opposite is the case.

With regards to the specific technology scenarios, a number of renewable technologies have been studied by the Forum for Renewable Energy Development in Scotland (FREDS), a group established by the Scottish Executive. Their report in 2005 (FREDS, 2005), estimated that the previous target of 40% of electricity generated from renewable sources was consistent with an installed renewable capacity of 6GW. Table 1 above shows that, as of May 2010, renewable electricity generation capacity in Scotland is 3.85GW. The higher target for renewable electricity generation described above would therefore suggest a higher installed renewable capacity.

On the specific renewable technologies, the report notes that while onshore wind is likely to provide much of the new renewable capacity, “assuming a range of technical and economic issues can be overcome, other technologies should also be capable of playing an important part by 2020” (FREDS, 2005, p. 11). That same report noted that an estimated wave and tidal practicable resource off Scotland was around 1300MW installed capacity. The most recent study of the wave and tidal resource in Scotland (FREDS: MEG, 2009), illustrated three possible deployment path scenarios for marine capacity – ranging from 500MW to 2000MW by 2020.

4.2 Scenarios from 2010

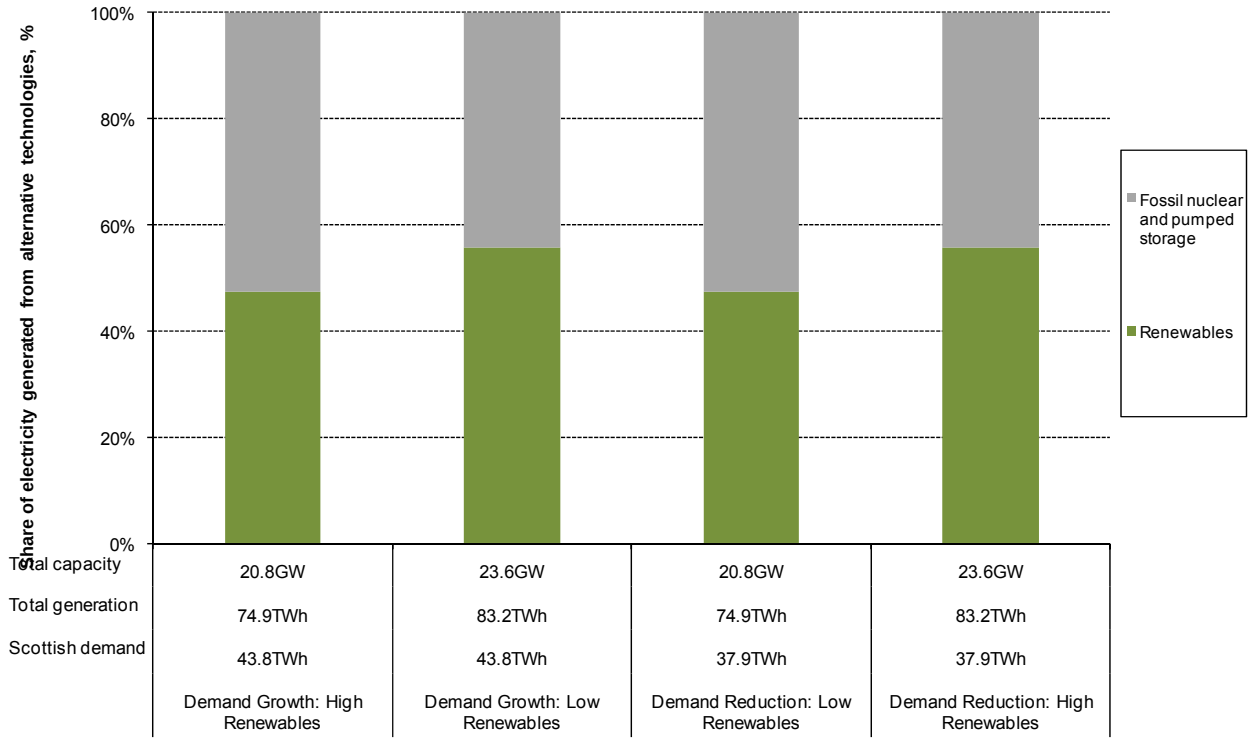
As this paper was in preparation, Scottish Renewables published commissioned work produced by Garrad Hassan (2010). This coincided with the announcement that the Scottish Government’s target for renewable electricity would increase from 50% by 2020 to 80% by that same year. Their report details four scenarios, also for 2020, in which this

figure is exceeded. The four scenarios combine two in which demand is lower, two in which demand is higher, and in each of these four cases, there is either “high” or “low” renewable development.

These results are shown graphically in Figure 4. The publication does not identify the contribution to Scottish electricity generation from individual technologies. We are therefore unable to disaggregate by technology as in Figure 3. This report shows how even within a short period of time, the future shape of the electricity generation mix in Scotland is predicted to be radically different from a few years previous. Note, for example, the huge differences in the capacity figures between Figures 3 and 4. Scottish demand estimates are broadly comparable, as is the broad pattern of electricity generation. The larger capacities shown in Figure 4 account for the significant increase in the ratio between electricity generated from renewable sources in Scotland and Scottish electricity consumption.

Further, considering the Scottish electricity generation mix explicitly as a portfolio, implies a rather different perspective that simply considering the individual technologies within that portfolio. As is shown in Allan et al (2010c), renewable technologies, including wave and tidal stream, can help to reduce the price variability of an electricity mix largely due to their zero correlation with the price of fuel inputs. In that paper we find that increasing the share of renewables in the Scottish generation mix can allow the cost variability of electricity to be reduced without any increase in the overall electricity price.

Figure 4: Generation mixes in each of the four Garrad Hassan (2010) scenarios



5. Conclusions

The Scottish electricity generation mix has seen radical change over the last decade. It has been transformed by a rapid development of renewable energy capacity, largely coming from onshore wind. Moreover, it is likely that over the next decade, for both technical and policy reasons, the electricity mix will change as never before. Strong support for alternative renewable technologies such as offshore wind, wave and tidal is likely to bring new capacity in these technologies –. Similarly, decisions taken about non-renewable technologies will be crucial for the future shape of the Scottish generation mix. With electricity demands likely to continue to increase over time, meeting these from a portfolio of generation technologies would be one way by which the energy policy goals of energy security, reduced environmental damage and enhanced economic development could be stimulated.

We note, however, that the EU Emissions Trading Scheme (EU ETS) deals with the allocation of the right to pollute across the EU. The rationale for Scottish Government ambitions for renewables therefore should be seen in light of

this. By being members of the EU ETS, Scotland's targets for the sectors "covered" by this mechanism (which includes the energy sectors) are met.

Accordingly, renewables policy does not directly assist the achievement of (domestically set) emissions reductions targets. Against this background, renewables must be regarded as contributing to the other goals of energy policy, such as security and supply and economic development through new low carbon technologies. This would be consistent with energy, particularly renewables, being a "key sector" in the Scottish Governments Economic Strategy (Scottish Government, 2007). See McGregor et al (2010) elsewhere in this special issue for more discussion of the relative roles played by legislation in Scottish climate change policy.

Recent work (e.g. Allan et al, 2008b, Gilmartin et al, 2010) has begun to quantify the potential for Scottish and UK economies respectively to be stimulated by renewable energy development, and the exporting of knowledge and technical components to service this expanding industry. This highlights, among other things, that the next decade could be crucial for Scotland capturing a significant share of a worldwide market for renewable technologies, with all the knock-on benefits to the Scottish economy.

The Scottish generation mix has evolved over the last ninety years through the development of hydropower from the glens, coal and nuclear facilities around the coasts, and the recent surge in onshore wind development, now beginning to move offshore. Further radical change seems likely in the next decade offering both significant risks and opportunities for Scotland.

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Endnotes

[1]Although, strictly, the Scottish Government is required to consider each application to build a new nuclear facility in Scotland on its own merits.

[2]The impact of these proposals on the levelised costs of wave and tidal electricity is discussed in Allan *et al* (2010b).

[3]As of September 2009, £2.946 million had been spent on WATES projects and their associated infrastructure for testing. It is anticipated that all the £13 million will be spent by March 2011.

[4]The details of the prize are the following. "£10 million will be awarded to the team that can demonstrate in Scottish waters a commercially viable wave or tidal energy technology that achieves a minimum electrical output of 100 GWh over a continuous 2 year period using only the power of the sea and is judged to be the best overall technology after consideration of cost, environmental sustainability and safety" (Scottish Government, 2008). The prize is intended to be awarded in Spring 2015, following the assessment of qualifying marine generation between January 2010 and December 2014.

[5]Regardless of whether the electricity generated is exported to the national grid.

[6]The private sector study (Murray, 2009) was based on research prepared by Garrad Hassan.