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A report for UKERC by
UKERC Technology & Policy Assessment Function

Low carbon jobs:

The evidence for net job creation from policy support for energy efficiency and renewable energy

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November 2014 v. 2

REF UKERC/RR/TPA/2014/002

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Preface

This report was produced by the UK Energy Research Centre's (UKERC) Technology and Policy Assessment (TPA) function.

The TPA was set up to inform decision-making processes and address key controversies in the energy field. It aims to provide authoritative and accessible reports that set very high standards for rigour and transparency. The subject of this report was chosen after extensive consultation with energy sector stakeholders and upon the recommendation of the TPA Advisory Group, which is comprised of independent experts from government, academia and the private sector.

The primary objective of the TPA, reflected in this report, is to provide a thorough review of the current state of knowledge. New research, such as modelling or primary data gathering may be carried out when essential. It also aims to explain its findings in a way that is accessible to non-technical readers and is useful to policymakers.

The TPA uses protocols based upon best practice in evidence-based policy, and UKERC undertook systematic and targeted searches for reports and papers related to this report's key question. Experts and stakeholders were invited to comment and contribute through an expert group. The project scoping note and related materials are available from the UKERC website, together with more details about the TPA and UKERC.

About UKERC

The UK Energy Research Centre is the focal point for UK research on sustainable energy. It takes a whole systems approach to energy research, drawing on engineering, economics and the physical, environmental and social sciences.

The Centre's role is to promote cohesion within the overall UK energy research effort. It acts as a bridge between the UK energy research community and the wider world, including business, policymakers and the international energy research community and is the centrepiece of the Research Councils Energy Programme.

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Executive Summary

Introduction

'Green' sectors account for as many as 3.4 million jobs in the EU, or 1.7% of all paid employment, more than car manufacturing or pharmaceuticals. Given the size of the green jobs market, and the expectation of rapid change and growth, there is a pressing need to independently analyse labour market dynamics and skills requirements in these sectors. What is more controversial is the question of whether policy driven expansion of specific green sectors actually *creates* jobs, particularly when the policies in question require subsidies that are paid for through bills or taxes. There are strong views on both sides of this debate. Politicians often cite employment benefits as part of the justification for investing in clean energy projects such as renewables and energy efficiency. Such claims are often backed up by project or sector-specific analyses. However, other literature is more sceptical, claiming that any intervention that raises costs in the energy sector will have an adverse impact on the economy as a whole.

The UKERC Technology and Policy Assessment (TPA) theme was set up to address such controversies through comprehensive assessment of the current evidence. This report aims to answer the following question:

> *"What is the evidence that policy support for investment in renewable energy and energy efficiency leads to net job creation in the implementing regions?"*

The focus on net jobs here is important: whilst it is clear that jobs can be created at a local scale by spending money on new infrastructure projects, other jobs may be displaced if the new project provides activities or services that would otherwise have been provided elsewhere in the economy. Analysis of net jobs therefore needs to take account of both jobs created and jobs displaced.

Counterfactuals

In the case of electricity generation, where new sources of supply may be needed in order to meet growing demand, the calculation of net employment impacts needs to take account of *counterfactuals* – i.e. what other kind of power generation sources would have been built instead if the country were not following a green policy pathway? The most optimistic assessments of green job impacts tend to exclude consideration of counterfactuals, counting only the jobs directly attributable to the project concerned.

On the other hand, some of the most sceptical literature is based on a rather aggressive definition of counterfactual which compares green energy investments with the most labour-intensive sector in the economy (e.g. construction) on the basis that if economic stimulus were the sole justification of policy, then interventions should be focussed on sectors with the highest employment impact per pound invested. However, assuming that policy-driven investment could flow unrestricted between very different sectors in this way, does not seem realistic in the UK context. Here, electricity policy options tend to be based on influencing companies' investment decisions regarding their choice of technology to meet a particular level of generation capacity.

For the purposes of this study, the counterfactual is therefore defined within the electricity sector only. We compare the jobs impact of investing in renewables and energy efficiency with the jobs impact of investing in an equivalent amount of fossil-fuel plant. For this study, we convert different types of job (e.g. short-term manufacturing and construction jobs and long-term operation and maintenance jobs) to a single measure of full-time long term job equivalents. In order to measure labour intensity, we calculate an indicator of jobs per annual GWh produced – this compares generation sources on a like-for-like basis in terms of their physical scale. We also compare job intensity figures for short-term job impacts, which may be particularly relevant for assessing the potential for economic stimulus interventions.

Modelling employment impacts

The methodologies used in the literature to estimate job impacts are reviewed. Primary data is often gathered through case studies, together with questionnaires and supply-chain surveys. Studies often include not just direct employment impacts, but also the wider ripple-through indirect effects of increased demand in the supply chain, as well as the induced effect of higher spending potential for those households that have benefitted from the higher employment rates. The most common analytical approach for these wider effects is input-output modelling. Studies also address wider macro-economic impacts through computable general equilibrium (CGE) modelling, or macro-econometric approaches. The pros and cons of each approach are reviewed in the report.

The quantitative evidence base comes from two main different types of literature. The first (comprising the majority of the literature surveyed) are studies where authors provide estimates of gross job impacts of individual projects for specific types of generation. To get an approximate estimate of net job impacts, we then compare across different studies the gross job impacts of investing in renewable energy and energy efficiency with the gross job impacts of investing in fossil fuel plant. In the second type of literature, authors explicitly calculate the net job impacts of renewables and energy efficiency compared to fossil fuels, giving us a direct indication of the net impacts. This was a smaller set of literature, but produced a roughly similar result to the first set of literature, giving some additional confidence in the overall conclusion.

The evidence on job creation

Based on a systematic review of this literature, there is a reasonable degree of evidence that in general, renewable energy and energy efficiency are more labour-intensive in terms of electricity produced than either coal- or gas-fired power plant. This implies that at least in the short-term, building new renewable generation capacity or investing in greater energy efficiency to avoid the need for new generation would create more jobs than investing in an equivalent level of fossil fuel-fired generation. The magnitude of the difference is of the order of 1 job per annual GWh produced.

To put this into perspective, total electricity supply in the UK is around 375,000 GWh, whilst total employment (full-time and part-time) in the UK electricity sector as a whole is 136,000 , putting the average employment intensity for the sector as a whole at around 0.4 jobs/annual GWh. A marginal increase in labour intensity of 1 job per annual GWh implied by a shift from fossil fuels to renewables or energy efficiency is therefore substantial. There are considerable variations between technologies, with wind power appearing to be relatively less labour-intensive, whilst solar and energy efficiency investments appear more labour-intensive.

Whilst the evidence seems reasonably robust that renewables and energy efficiency are in general more labour-intensive than fossil fuels, this does not automatically mean that preferential investment in these technologies will lead to higher employment in the economy as a whole. Short-term employment impacts of diverting investment from fossil fuel generation to renewables and energy efficiency may very well be positive. However, long-term impacts will depend on how these investments ripple through the economy, and in particular the impact on disposable household incomes.

Macroeconomic conditions

The answer to this question depends very much on macroeconomic conditions. In a depressed economy in which aggregate demand is low compared to potential supply of goods and services (creating a so-called 'output gap'), then Keynesian measures of stimulating additional employment in particular sectors are very likely to lead to higher overall employment, and it makes sense to focus such efforts on more labour-intensive options. On the other hand, in an economy which is closer to 'equilibrium' conditions, with close to 'full employment', the room for such manoeuvres is more limited, and government-led investments may crowd out private investment leading to lower-than-expected net employment results.

Fiscal and monetary stimuli therefore have a role to play during periods of recession, but can do more harm than good during periods of full employment. Good policy design is therefore a matter of timing. However, estimating the duration and depth of a particular period of recession is far from an exact science. Lags in the effects of policy can exacerbate the difficulties. Results from the few studies that have used computable general equilibrium models, reflect this dichotomy.

Some studies indicate a negative employment impact of renewables, while others indicate a positive impact, the differences largely reflecting the authors' *a priori* assumptions regarding these pivotal macroeconomic issues. The more nuanced studies show positive employment impacts in the short-run due to the higher job intensity, with negative effects later on as price effects feed into economic behaviour. However, none of the studies reviewed factored in any externalities of fossil fuel plant, such as environmental impacts or energy security considerations.

Policies that have impacts beyond the time horizon of the current business cycle lock-in the economy to a particular set of behaviours that go beyond their initial stimulus impacts. This is particularly true for decisions in the electricity sector which concern long-lived strategic infrastructure. In these cases, it is important to assess the balance of costs and benefits to the economy in terms of the impact on growth potential. When designing stimulus programmes, it makes sense to support technologies and projects that support technological progress in the long-term, because if they have a persistent impact on the economy beyond the timeframe of the direct stimulus effects, they should also help contribute to long-term growth. In this longer-term context, labour intensity is not in itself economically advantageous, as it implies lower levels of labour productivity (economic output per worker), which could adversely impact prospects for economic growth.

Therefore, the employment characteristics that matter in the long-run are not how many jobs are created per unit of investment, but whether or not the investment contributes to an economically efficient transition towards the country's strategic goals, taking account of externalities such as environmental impacts and energy security considerations.

Conclusions

In conclusion, there is reasonable evidence from the literature that renewables and energy efficiency are more labour-intensive than fossil-fired generation, both in terms of short-term construction phase jobs, and in terms of average plant lifetime jobs. Therefore, if investment in new power generation is needed, renewables and energy efficiency can contribute to short-term job creation so long as the economy is experiencing an output gap, such as is the case during and shortly after recession.

In the long-term, if the economy is expected to return to full employment, then 'job creation' is not a meaningful concept. In this context, high labour intensity is not in itself a desirable quality, and 'green jobs' is not a particularly useful prism through which to view the benefits of renewable energy and energy efficiency investment. What matters in the long-term is overall economic efficiency, taking into account environmental externalities, the desired structure of the economy, and the dynamics of technology development pathways. In other words, the proper domain for the debate about the long-term role of renewable energy and energy efficiency is the wider framework of energy and environmental policy, not a narrow analysis of green job impacts.

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List of abbreviations and acronyms

CCGT	Combined Cycle Gas Turbine
CCS	Carbon Capture and Storage
CES	Constant Elasticity of Substitution
CSP	Concentrated Solar Power
DECC	Department of Energy and Climate Change
DSGE	Dynamic Stochastic General Equilibrium (model)
DSM	Demand-Side Management
EE	Energy Efficiency
ESCO	Energy Service Companies
EU	European Union
FTE	Full Time Equivalent (jobs)
GBP	British Pounds (£)
GWh	Gigawatt hour
IO	Input Output (tables)
MRIO	Multi-Regional Input-Output (tables)
MW	Megawatt
MWp	Megawatt peak
O&M	Operations and Maintenance
OECD	Organisation for Economic Cooperation and Development
PV	Photovoltaics
RE	Renewable Energy
RGGI	Regional Greenhouse Gas Initiative
SAM	Social Accounting Matrix
TPA	Technology and Policy Assessment (a function of the UKERC)
UK	United Kingdom
US	United States of America
UKERC	UK Energy Research Centre
VAR	Vector AutoRegression

Introduction

1

Why study green jobs? At one level, the answer is obvious. According to some estimates, green jobs already account for 3.4 million jobs in Europe (Rademaekers *et al*., 2012), more than in car manufacturing or the pharmaceuticals industry. If one accepts the need for 'greening' the economy, then the impacts of such a transition on the labour market will clearly need to be understood. In particular, if the new 'green' sectors are to grow rapidly, there needs to be a sufficient skills base and industrial capacity to facilitate this growth.

During the boom in wind power in the late 2000s, for example, there was evidence of a shortage of suitably qualified engineers and maintenance staff across Europe to sustain the rapid growth of installations (Blanco and Rodrigues, 2009). Other labour market impacts that need to be understood are the potential dislocations that might occur in the 'losing' sectors. These are important issues for economic and political analysis to investigate.

However, there is a second and more contentious strand to the green jobs debate, which is the focus of this report. Are there, as some proponents claim (Pollin *et al*., 2009, UNEP, 2008, Bezdek, 2009), benefits to employment from clean technologies that arise *irrespective* of their environmental case? This claim is more controversial, with critics (Huntington, 2009, Morriss *et al*., 2009, Michaels and Murphy, 2009) suggesting that the imposition of more expensive technologies will, overall, tend to be economically damaging. This report aims to investigate the evidence on both sides of this debate.

In some contexts (e.g. when measuring the size of the sector), it is important to explicitly define what is meant by a 'green job'. Some categories of job will be obviously 'green'; installing and maintaining solar panels or wind turbines, for example. Others are less obvious – are the lorry drivers who deliver the solar panels to site carrying out a green job? For the most part, these definitional issues are of less concern in this report. The issue we address here is whether 'green' policies lead to the creation of additional jobs. As long as the jobs contribute to fulfilling the aims of the policies, then they count as job creation, irrespective of whether they individually would be considered as being particularly 'green'. To further avoid controversies around definitional issues, the report focuses on a relatively narrow subset of 'green' policies, namely support for renewable energy[1] and energy efficiency.

The specific research question that this report aims to address is:

> *"What is the evidence that policy support for investment in renewable energy and energy efficiency leads to net job creation in the implementing regions?"*

The question reached particular policy relevance at the onset of the financial crisis when governments were considering how to spend economic stimulus money. At this time, issues of how many jobs would be created by different investment pathways were paramount. During his election campaign in 2008, President Obama promised to invest $15bn per year in renewable energy over the next decade, thereby:

> *"...creating five million new green jobs that pay well, can't be outsourced and help end our dependence on foreign oil".*

The issue of job creation has remained politically prominent throughout the subsequent period of recession and slow recovery. To some extent, the discourse around the employment impact of renewables may be symptomatic of a period of waning public interest in climate change issues. The title of a November 2013 press release from DECC[2] on renewable energy gives some clue as the ordering of political priorities: *"Renewable energy: delivering green jobs, growth and clean energy"*. The press release highlights that the investment in the renewable electricity sector since 2010 had the potential to support over 35,000 jobs[3]. Likewise for UK's flagship energy efficiency programme, the Green Deal was predicted in September 2010[4] to create up to 250,000 green jobs by 2030.

However, the evidence underpinning this debate is far from clear cut. The UKERC Technology and Policy Assessment (TPA) theme was set up to address such controversies through comprehensive assessment of the current evidence. It aims to provide rigorous and authoritative reports, while explaining findings in a way that is useful to policy makers.

The objectives of this report are to:

- clarify the relevant conceptual, definitional and methodological issues underlying the low carbon jobs debate;
- identify the strengths and weaknesses of different methodological approaches for estimating employment impacts;
- assess the level of the uncertainty associated with these estimates and the factors contributing to that uncertainty;
- identify the assumptions behind different studies and the reasons for their different conclusions;
- identify the research and data gaps; and
- draw conclusions on the employment implications of selected climate policies, including the conditions under which they may lead to net job creation in OECD economies over the short, medium and long-term.

1 In practice, much of the focus is on comparing renewable electricity generating technologies with the fossil-fuelled alternatives.

2 www.gov.uk/government/organisations/department-of-energy-climate-change

3 www.gov.uk/government/news/renewable-energy-delivering-green-jobs-growth-and-clean-energy

4 www.gov.uk/government/news/green-deal-to-create-green-jobs

The report focuses on OECD countries. This primarily reflects the nature of the evidence base, with the vast majority of the literature focusing on countries within the OECD. We consider Full Time Equivalent (FTE) jobs, as again this is standard within the literature.

We exclude policies which use carbon pricing from the report. This includes carbon taxes and emissions trading schemes. Whilst carbon pricing mechanisms may be considered important, or even essential, the economic impact of these mechanisms is well understood, the relevant literature is extremely large and comprehensive reviews of this literature have been published previously. This report focuses instead on other forms of support, including subsidies efficiency standards, and feed-in tariffs.

Section 2 introduces the key concepts used in the green jobs debate, clarifies terminology, and explains the rationale behind the approach and metrics used in this report for comparing jobs estimates between different publications.

Section 3 examines the main models used in the literature to estimate employment impacts, identifying strengths and weaknesses of key methodological approaches. This section also summarises a longer and more technical discussion provided in a background paper written by Strathclyde University for this study (Allan *et al.*, 2012), which is available on the UKERC website[5].

Section 4 provides a quantitative comparison of estimates from the literature of employment impacts associated with investment in renewable energy and energy efficiency, providing the main empirical evidence of the study.

Finally **Section 5** summarises the findings of the assessment.

The **Appendix** to this report provides details of the research methodology, and the list of publications included in the systematic literature review.

5 www.ukerc.ac.uk/support/tiki-index.php?page=Low+Carbon+Jobs

Key Concepts

2

This section provides clarification of some key concepts with the aim of providing a better understanding of the claims and counter-claims regarding our research question. The literature can broadly be divided into two branches. The first branch is what might be considered dedicated 'green jobs' literature, focussing fairly specifically on the types of issue raised in this report. Papers in this category form the large majority of papers captured in the systematic review because of the search terms used. No less important however are the broader macro-economic perspectives on employment, which tends to see issues around low-carbon transition within a wider and longer-term context.

The former is essentially based on a 'job counting' approach, attempting to quantify how many jobs are created by investments in renewable energy (RE) and energy efficiency (EE) as compared to other types of investment. In this approach, analysts have to be careful about what to include in the definition of a green job, the degree to which 'new' jobs create a ripple-through effect on the wider economy (either locally or nationally), and what (if anything) the investment is being compared to. The metrics used to count these jobs have an important impact on the analysis. These issues are explored in Section 2.1.

The latter takes an economy-wide perspective from the outset, and aims not to count 'green jobs' as such, but to look at the wider labour market impacts of green policies. Under this approach, the definition of a green job is not particularly relevant, what matters is whether overall jobs or other indicators of the labour market or the economy as a whole are impacted positively or negatively by RE and EE policies. These issues are explored in Section 2.2.

2.1 What are Green Jobs, and How can we Measure Them?

The definition of 'green jobs' can be controversial. Whilst jobs within some sectors may be clearly thought of as 'green' (e.g. renewable energy), others (such as those in waste management or nuclear power) may be more contentious. However, it is not the intention of this report to resolve this particular definitional issue. The focus of this report is the employment impact of 'green policies'. Any job created or destroyed as a result of a green policy counts towards this arithmetic, irrespective of its inherent 'greenness'. We avoid the subsequent question of what counts as a 'green policy' by focussing on a particular subset of green policies, namely support for renewable energy and energy efficiency. Other definitional issues need to be resolved in order to address our research question, which are the focus of this section. These are generic to the analysis of employment impact of any green policies, not just energy efficiency and renewables policies.

2.1.1 'Gross' vs. 'Net' – the effect of displaced jobs

The first and most important definitional issue to address is the distinction between 'gross' and 'net' job impacts. Gross effects include only the positive impact on employment associated with a particular investment. It is clear that gross jobs can in general be created when money is spent on projects that require manufacturing, installation, operation and maintenance of new equipment.

What is relevant to the research question of this study is whether net jobs can be created when the potential negative impacts of those projects on the wider economy is taken into account. In particular, it is important when considering the net employment impacts of a RE or EE investment to consider jobs that might be displaced in other parts of the economy as a result of the investment. For example, several studies (Allan *et al.*, 2007b, Groscurth *et al.*, 2000, Lenzen and Dey, 2002, Wei *et al.*, 2010) offset the number of gross jobs created through additional RE deployment by the implied number of jobs that would be lost in other parts of the power sector due to less power generation needed from coal and gas generation, for example.

The degree to which displaced jobs are considered varies considerably in the literature, and depends on scope of study, making comparison between studies difficult. Some of the factors affecting the extent of displaced jobs include:

- **Source of the money.** Most bottom-up studies implicitly or explicitly assume that the money required for the RE or EE investment is 'new' money that otherwise would not have been spent. This perspective arises largely because of the government stimulus packages responding to the financial crisis that spawned much of the green jobs debate. This assumption is important, because if the money really is additional, then displaced job impacts are more likely to be limited to a small subset of the economy. For example, expanding wind power, or implementing greater household energy efficiency will tend to reduce demand for traditional fossil-fired generation, reducing jobs to some extent in that sector. In this context, a relatively restricted 'job counting' analysis of the positive and negative impacts of these projects within the energy sector is probably adequate. If on the other hand the money is assumed to come from individuals, then household expenditure is much more likely to be affected. This requires a much broader assessment of the employment implications in the wider economy, making simple 'job counting' approaches less appropriate.

- **Geographical scope.** The research question for this study considers the prospects for creating net jobs '*…in the implementing regions*'. If the geographical scope of a 'region' is drawn sufficiently tightly, then many of the displaced jobs could fall outside of that boundary. Indeed, many studies exclude displaced jobs on this basis, particularly those focused on the potential for regional development. If a tight geographical boundary is used, then this also affects the question about the 'source of the money' discussed above, since investments in RE and EE that are paid for by consumers at a national level, will be experienced as 'additional' new money from the perspective of the local community where the projects are built. Geographical scope is also important when considering the job implications of imports or exports. For example, investments might result in the potential for a region of the UK, or the UK as a whole, to export RE / EE equipment or additional renewable energy to other regions or other countries, which could offset some of the displaced job impacts.

  Whilst a small geographical boundary might reduce the number of displaced jobs, it also reduces the extent to which the economic benefits of the project will remain within that boundary. The 'ripple-through' effects on the wider economy are therefore more likely to leak outside of the region being assessed when that region is small (see for example Lesser (2010)). This is linked to the concept of induced jobs discussed in the next section. In particular, the local share of provision of equipment and labour can dominate job impacts of localised assessments, and often vary considerably: e.g. in comparing impacts of wind development in two different counties in Arizona, Williams *et al.* (2008) note that:

  > *"It is an interesting paradox that a county with a more rural and less developed economy will receive less economic benefit from the construction and operations of a wind energy project than a county with a more developed economy. This is because of fewer workers, equipment and supplies found within the rural county, and also less induced economic benefit."*

- **Timescale.** The timescale over which job impacts are considered is important, since there may be a delay between creating jobs in one sector and displacing jobs in another. For example, while RE projects are being built, they are not producing any electricity, and therefore not displacing any jobs in the rest of the electricity sector. Also typically consumers do not start to pay for the renewable energy until the project has been completed and is generating (see for example Hillebrand *et al.* (2006)). This delay could be used as a justification for excluding analysis of displaced jobs in the context of assessing short-term stimulus effects of RE spending, though more typically it is the longer-term impacts that are of interest to policy-makers.

  Note that the impact of the timescale also depends on type of measure. EE expenditures may be upfront, but the main economic and employment benefits come later as savings accumulate over time, leading to greater household disposable income. For example, energy savings from more efficient vehicles take time to accumulate because of the time taken for the new cars to penetrate the vehicle fleet. For EE assessments, job impacts therefore typically tend to be higher in the long-run than they are in the short-run (see for example Scott *et al.* (2008)).

2.1.2 Direct, indirect and induced

When thinking about job impacts of RE and EE investments, an important issue to address is how far should the analysis include the economic 'ripples' of this investment in creating indirect and induced jobs? The following definitions underpin these concepts as used in the literature.

Direct employment refers to those jobs that that arise directly as a result of the investment. There is no single accepted definition in the literature, but a useful description is provided by Wei *et al.* (2010) who includes in this category "…jobs created in the design, manufacturing, delivery, construction/installation, project management and operation and maintenance of the different components of the technology, or power plant, under consideration".

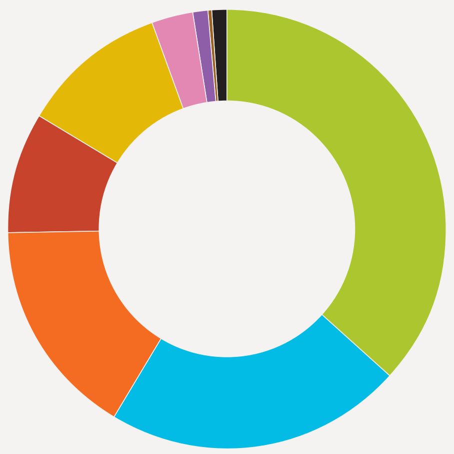
The definition of direct jobs may vary depending on the timescale and geographical scope of the study. For example, short-term impacts may focus on manufacturing and installation jobs, whilst longer-term analysis would also include ongoing operation and maintenance jobs. Geographical scope may also be important in determining whether or not manufacturing jobs are included in the analysis if equipment is imported into the region being assessed. Direct employment impacts are typically measured by surveying the companies contracted to complete the specific project (Chapter 3).

Displaced direct jobs are even less well defined in the literature, but in the short-run would include the jobs offset at existing fossil-fired generation plant, whilst a longer-run analysis would include the direct jobs that would have been required to build new fossil-generation plant if the RE or EE projects had not been implemented.

A breakdown of different types of direct employment in the wind industry based on a survey of firms across Europe (Blanco and Rodrigues, 2009) is presented in Figure 1.

Figure 1: Direct employment in EU wind sector by type of company surveyed

Percentage (%)



Manufacturers	37%	Consultancy engineering	3%
Component Manufacturers	22%	R&D/University	1%
Developers	16%	Financial/ Insurance	0.3%
IPP/Utility	9%	Others	1%
Installation/repair/O&M	11%		

Source: Blanco and Rodrigues (2009)

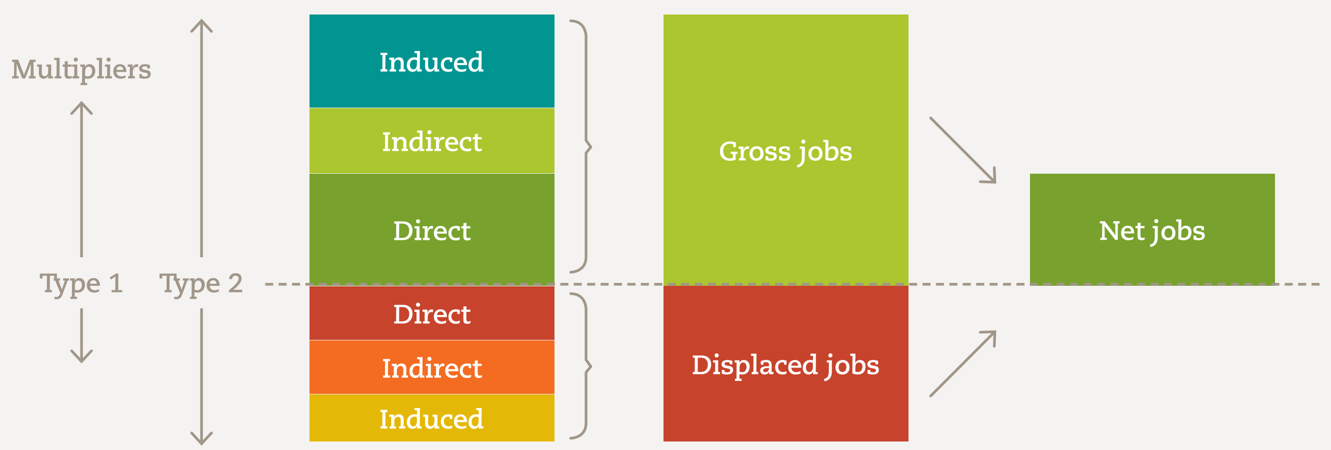
Indirect employment commonly refers to the jobs created within the supply chain supporting a specific project. In the construction of a wind farm this would include the jobs in companies providing raw materials to wind turbine manufacture (steel and other metals, basic electronic components etc.), and suppliers of supporting structure materials such as steel or concrete for foundations. Indirect jobs are further removed from the end-use, and may not in any normal sense of the word be considered a 'green job', except insofar as they arise from the initial green policy stimulus. Indirect employment impacts are sometimes measured through supply-chain surveys, or more commonly are estimated using macroeconomic modelling techniques (Chapter 3). ***Displaced indirect*** jobs would include any offsets due to a reduction in these similar supply chain jobs (steel, concrete etc.) that occur because of the associated reduction in build-rate of fossil-fired plant that are displaced by the RE or EE projects.

Induced employment commonly refers to jobs created as a result of the increased household expenditure of direct and indirect employees. The wages paid to direct and indirect employees are spent on goods and service, supporting further employment. According to Wei *et al.* (2010) this can include non-industry jobs created (e.g. teachers, retail jobs, postal workers etc.) whilst when discussing energy efficiency, a large portion of the induced jobs are the jobs created by the household savings and implied increase in expenditure on other goods & services. Induced employment is generally estimated using macroeconomic modelling techniques (Chapter 3). Accounting for ***induced displaced*** jobs would need to take account of the impact on wider household expenditures outside the set of people who have benefited either directly or indirectly from the project. For example, if the cost of energy goes up for consumers in the wider economy as a result of RE or EE programmes, then this could lead to a reduction in spending on other goods and services, with an associated negative impact on jobs.

The factor by which indirect or induced jobs increase for a given increase in direct jobs is the ***multiplier***. This multiplier is typically calculated on the basis of Input Output (IO) tables, a technique discussed in greater detail in Chapter 3 Indirect job multipliers are often referred to as 'type 1', whilst induced job multipliers are referred to as 'type 2'.

These concepts are summarised schematically in Figure 2.

Figure 2: Schematic showing the relationship between different types of job impact, showing for illustrative purposes a positive net impact (negative net job impacts are also possible depending on the scale of displaced jobs)



Varma and Medhurst (2007) provide analysis of how these factors vary across Europe in relation to environmentally-related expenditure (see Table 1). In terms of the factors that affect these multipliers, the authors note:

> *"In the UK for example, Type I multipliers are much larger than in Greece. A closer inspection reveals that the environmentally-related sectors in the UK have greater links to other sectors (buys more input from other sectors) compared to Greece. Moreover the UK's import to output ratio in these sectors is relatively lower than the ratio in Greece. This means that when shocks are entered to the environmentally-related sectors, more are passed on to other sectors domestically within the UK than the amounts that get passed on domestically in Greece."*

This highlights the importance of the geographical boundary of the region being assessed, as well as the particular economic conditions that exist within that boundary.

Table 1: Environment Related Employment Multipliers

	Employment multiplier	
	Type I	Type II
EU-27	**1.49**	**1.70**
Belgium	1.48	1.60
Denmark	1.50	1.75
Germany	1.50	1.74
Greece	1.22	1.25
Spain	1.44	1.60
France	1.57	1.84
Ireland	1.17	1.26
Italy	1.35	1.40
Luxembourg	1.32	1.45
Netherlands	1.54	1.78
Austria	1.29	1.38
Portugal	1.37	1.48
Finland	1.59	1.74
Sweden	1.41	1.59
UK	1.83	2.37
Czech Republic	1.79	1.97
Estonia	1.72	1.93
Cyprus	1.22	1.29
Latvia	1.63	1.69
Lithuania	1.32	1.36
Hungary	1.61	1.72
Malta	1.32	1.75
Poland	1.66	1.74
Slovenia	1.41	1.52
Slovakia	1.83	1.94
Bulgaria	1.42	1.56
Romania	1.45	1.50

Source: Varma and Medhurst (2007)

2.1.3 Opportunity costs & counterfactuals

One of the key determinants that separates the two sides in the green jobs debate is whether or not the 'green' investment is compared to some other kind of investment that could have been made instead, and if so, what kind of investment that is assumed to be. These alternative jobs which could have been created with the same investment money are referred to as ***opportunity*** cost jobs, and the alternative scenario is a ***counterfactual***.

Proponents of green jobs tend to exclude opportunity costs on the basis that they are aiming to assess whether or not a particular RE or EE intervention will create jobs or not *in its own right*. The question of whether these are the *maximum* number of jobs that could have been created with that money is considered to be outside the scope of the policy questions addressed by such studies.

By contrast, green job sceptics focus more strongly on opportunity costs, noting that if job creation is the main driver for the economic stimulus being considered, then there are other sectors in which the same money would be likely to create more jobs. By choosing counterfactuals for example in the construction industry, some papers (see for example Huntington (2009)) demonstrate that with the inclusion of opportunity costs, green investments lead to significant net job destruction.

The choice of whether or not to include opportunity costs (and if so, the choice of counterfactual) is subjective, and depends on the policy question being addressed. Unfortunately, it also often depends on the political message that the authors wish to convey, making it difficult to determine a purely factual basis on which to interpret the literature.

2.1.4 Short-term vs. Long-term Jobs

Direct jobs associated with a particular investment may be full-time or part-time, and may last anywhere from a few months to many years. The literature is not always clear about differentiating between these categories, despite the obvious differences in economic value. The main categories of direct jobs associated with RE and EE projects include:

- Manufacturing of equipment. This can include not just final products, but the wider supply-chain. The extent to which manufacturing jobs are captured within the scope of a particular study depends largely on its geographical boundary. Inclusion of manufacturing facilities in jobs estimates can have a large impact on the results.
- Construction and installation jobs. Construction and installation of RE plant are typically relatively short, lasting for only a few weeks in the case of rooftop solar or up to one or two years in the case of wind power but can be considerably longer for large hydro-electricity projects. These short-term construction jobs may be important in terms of an economic stimulus effects because the construction phase typically employs many more people than the operational phase, but for much shorter periods of time.
- Operation and maintenance (O&M). This phase lasts as long as the lifetime of the plant, and can create stable long-term jobs. Studies with a reasonably wide geographical scope (e.g. national) are likely to include all the O&M jobs within the boundary, but very localised jobs may not do so. For example, Lantz and Tegen (2008) show that O&M jobs for wind farms may come from outside a particular region if they use mobile maintenance crews.

The different durations may serve a different type of economic purpose, with short-term jobs being more effective in terms of rapid economic stimulus, whilst long-run jobs may be more stable and therefore perhaps more desirable to employees. Despite these differences, most of the green jobs literature is concerned with identifying total job impacts, so a simple way is needed of converting to a common unit in order to be able to combine different types of job duration into a single job count.

One approach is to measure jobs in **full-time equivalent** (FTE) terms, and to assume that 1 'job' lasts for the duration of the plant lifetime (see for example Wei *et al.* (2010), Lantz and National Renewable Energy (2008)). This allows estimates that combine short-term construction jobs with longer-term operation and maintenance jobs. For example, a project which creates 30 construction jobs for 6 months and 3 full time jobs for the plant lifetime of 15 years would be counted as creating 30x0.5/15 + 3 = 4 FTE 'jobs'. The duration of jobs may be among the issues that are of policy interest (see next section), but often policy objectives are not sufficiently well defined to be able to distinguish between the relative benefits of jobs with different employment durations. Alternative approaches are taken by other authors (Caldés *et al.*, 2009; Simas and Pacca, 2014) who normalise jobs on an annual basis, such that they effectively report employment results in terms of job-years.

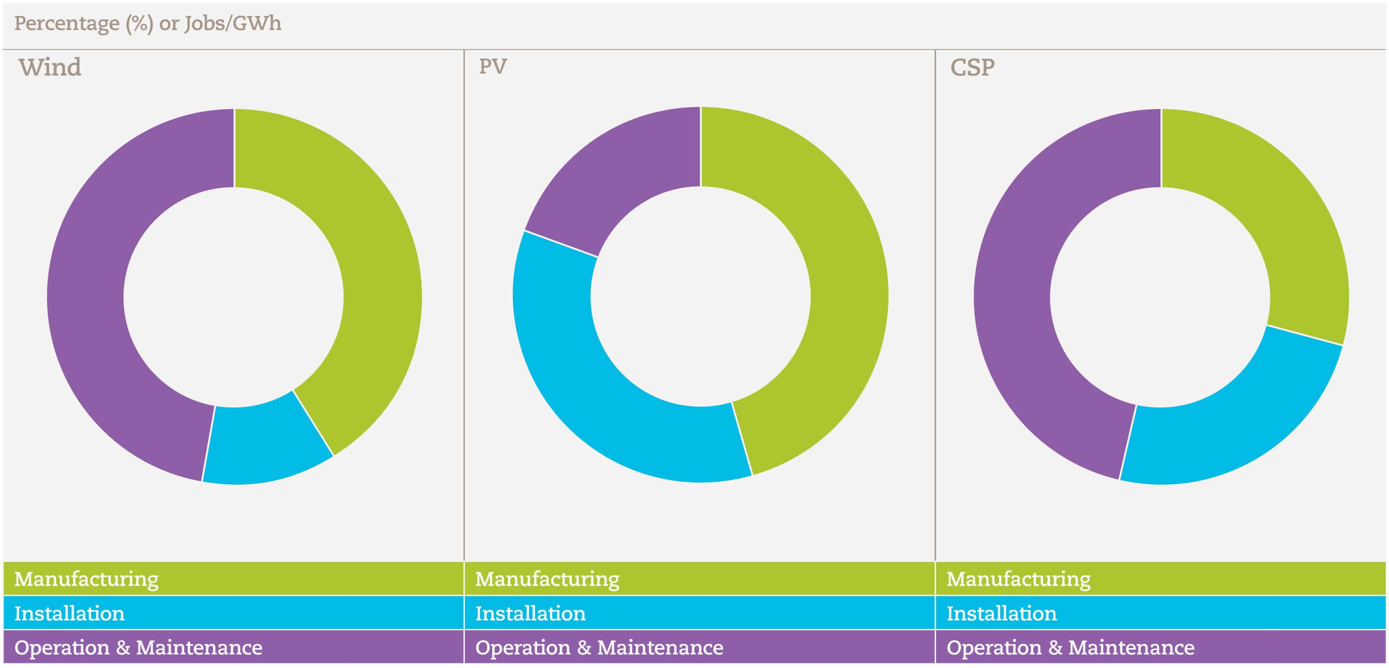
In this report, we take the former convention (as per Wei *et al.* 2010), and refer to 'jobs' as a short-hand for FTE long-term job equivalents lasting over the duration of the plant.

Nevertheless, it is worth keeping this distinction between short- and long-run effects in mind. Some publications make a particular effort to distinguish between these different job types. For example, Cameron and van der Zwaan (In Submission), provide a literature review of estimates of the breakdown of direct gross jobs between manufacturing, installation and O&M. The results of their survey are shown in Figure 3. The first three columns show the data as presented in the paper, with short-term jobs (manufacturing and installation) presented in terms of 'job-years/MW', and O&M in 'jobs/MW' extending over the plant lifetime.

The final three columns of Figure 3 convert these figures to the common unit used in this paper, namely 'jobs/annual GWh' using the same convention as for other papers in this review, as set out in Section 4.1.3. The pie charts in Figure 3 show the median values for each technology. These show that the existence of manufacturing facilities within the boundary of the jobs study will have a significant impact on the results. It is also interesting to note the different breakdowns between the technologies, with solar PV requiring considerably more labour for the installation phase per unit than the other two technologies. These results seem to confirm the findings above, that solar is more labour-intensive overall than wind.

Figure 3: Job breakdown between manufacturing, installation and O&M

	Manf job-yrs/MW	Inst job-yrs/MW	O&M jobs/MW	Manf	Inst	O&M	Total
				Jobs/annual GWh			
Wind							
Min	2.7	0.5	0.1	0.05	0.01	0.04	0.10
Median	3.9	1.3	0.2	0.07	0.02	0.08	0.18
Max	12.5	6.1	0.6	0.24	0.12	0.23	0.58
Solar PV							
Min	6	7	0.1	0.09	0.11	0.04	0.24
Median	16.8	13.2	0.3	0.26	0.20	0.11	0.57
Max	34.5	33	0.7	0.53	0.50	0.27	1.29
Solar CSP							
Min	4	6	0.2	0.04	0.06	0.08	0.17
Median	12.8	10.2	0.5	0.12	0.10	0.19	0.41
Max	21.6	14.4	1	0.21	0.14	0.38	0.72



Source: Cameron and van der Zwaan (In Submission)

The importance of the manufacturing sector is also noted by Simas and Pacca (2014), although they arrive at a smaller share of total employment in the manufacturing sector at around 25%, with construction taking a larger share in their figures at around 30%. This might reflect the more recent nature of the survey undertaken by Simas and Pacca, compared to the literature review of Cameron and van der Zwaan which encompasses papers over the past 10 years or so, and might include data for older (and smaller) turbine designs which could have a higher employment intensity per unit of electrical output.

2.1.5 Quality of Jobs and Distributional Issues

As stated in the research question, the focus of this report is on the total number of jobs created. However, there are many qualitative aspects of green jobs that are of interest from a political and societal perspective. These include issues such as whether those jobs are desirable in terms of pay, working conditions, skill level, who bears the cost of any externalities from the projects, and whether there are distributional effects associated with a shift towards green jobs. There is a wide-ranging literature on these topics which is beyond the scope of this report, some examples include:

- A survey of jobs in the Spanish renewable industries (Llera Sastresa *et al.*, 2010) found that the sector requires are relatively high share of technical specialisation in terms of the skills-set required.
- The distributional effects of such technological specialisation has been explored in work by Harper-Anderson (2012), who argues that in the push towards a green economy in the US, *"resource distribution has been uneven across geographic areas and demographic groups. Unfortunately, some of our nation's neediest people and communities are being left out of the green revolution"*.
- The higher returns to capital vs. returns to labour has tended to give rise to adverse wealth distribution in regards to RE investments as noted by Rose *et al.* (1982) in relation to geothermal power developments in California.

In the remainder of this report, issues relative to the quality of jobs are not explored further, as the emphasis is on total number of jobs rather than the type of job or equity of benefits. Nevertheless, these issues may be important for policy-makers to bear in mind when considering public acceptability and support for investments.

2.1.6 Measurement metrics

A final issue to consider is the choice of denominator used to calculate indicators. Dividing the number of jobs by some measure of the scale of activity allows projects/programmes of different sizes to be compared; giving some indication of their relative effectiveness in terms of job creation. For example, a common indicator used in the context of green stimulus packages is the number of jobs created per pound (or other currency) invested in the project/programme. In the context of renewable energy, alternative units commonly used include 'jobs per MW capacity installed' or 'jobs per MWh electricity generated'. The choice of metric used to measure job impacts can have a significant influence on results, and there is no standard approach in the literature; the choice of metric will often be made according to the particular political point being made, or on the policy issue being addressed.

Pros and cons of different indictors include:

- **Jobs/£ invested.** This is perhaps the most relevant indicator to use in the context of green stimulus funding to decide which projects/programmes would have the greatest employment impact per pound invested (see for example Huntington (2009). A disadvantage of this indicator is that it may not provide adequate resolution between capital costs vs. operating costs. For example, if stimulus funding is used to build projects, leaving on-going operating costs to be paid for by project beneficiaries or by the wider market, then this indicator would artificially make capital intensive plant appear less attractive.
- **Jobs/MW (installed or available).** Studies that look at the direct job impacts of a transition to a low-carbon electricity generation system tend to compare job intensities using a measure of activity relevant to the electricity sector. Installed capacity is often used, but is a rather crude measure because different technologies require very different levels of installed capacity to deliver the same amount of electricity. Some authors, for example Wei *et al.* (2010) correct for this by using the average expected capacity factors for different classes of technology to convert to a jobs/MW available indicator, making comparisons between technologies more appropriate. The cost of different technologies is not taken into account, making this indicator further removed from assessing wider economic impacts.
- **Jobs/MWh generated.** Another way of adjusting for the different levels of capacity factor is to use MWh generated as the denominator in the indicator, providing for a fairer comparison between different technology types. A disadvantage of this approach however is that it does not necessarily provide a good indicator of project quality *within* a particular

technology category. For example, according to this indicator, a wind farm in a poor location with low output would seem more attractive than a similar wind farm in a good location and high output (Cameron and Van der Zwaan, In Submission).

All these indicators share a common disadvantage as they look at projects/programmes solely in terms of their job impacts, whilst ignoring other associated costs or benefits. These other costs and benefits are likely to diverge significantly between project types, and are therefore difficult to compare. Often, they may be more significant in economic or social terms than the job impacts, making a focus on a narrow job indicator an inadequate way of prioritising projects/programmes.

In particular, these indicators raise the contested question of whether high labour intensity is a good thing or not. A project or programme with high jobs intensity may seem like an advantage from the point-of-view of a green stimulus programme, but they also indicate that labour productivity of the jobs are likely to be low, which could have negative consequences for the economy as a whole over the longer-term. This issue is bound up in the wider debate about the macro-economic impacts of jobs programmes, key concepts for which are discussed in Section 2.2.

2.2 Macroeconomic Perspectives and Concepts

Macroeconomic analyses have a different perspective, in that they usually are intended to address total net employment impacts across the economy, taking into account the wider impacts of RE & EE policies on labour market as a whole. Many of the issues discussed in the previous section regarding distinctions between net and gross jobs, definitions of green jobs and measurement metrics become irrelevant under this perspective, since everything is measured in terms of total employment and overall performance of the economy (i.e. in terms of GDP and income per household).

A macroeconomic approach solves some of the short-comings of the 'job counting' approach identified above. The question of whether individuals and firms will be better- or worse-off as a whole can be addressed more fully. In particular, these analyses can take account of the way in which RE and EE policies impact on energy costs and levels of disposable income, and how this feeds through to expenditure levels in the rest of the economy and the corresponding economic impact. In many ways, overall economic impact is the ultimate test for policy, making this kind of analysis attractive from the point of view of academic rigour.

However, macroeconomic approaches face problems of their own. Most importantly, the macroeconomic theories which describe the root causes of major episodes of unemployment are contested. Any attempt to model employment impacts has to make some fundamental assumptions about interactions between the labour market and the wider economy. Without a settled macroeconomic theory of the causes (and solutions) of unemployment, such analyses can only provide a partial viewpoint.

The most common modelling approach for macroeconomic analysis is to assume that the economy is in or close to equilibrium. Such approaches include for example a computable general equilibrium (CGE) model, or more advanced variants such as dynamic CGE model. However, Keynesian economics, which provides one of the leading theoretical bases for understanding unemployment effects, explicitly relies on the assumption that economies are out of equilibrium during periods of high unemployment. Such conditions are much harder to model. Whilst some relatively new approaches are being developed (such as dynamic stochastic CGE models and macroeconometric models briefly reviewed in Section 3.3) the review for this study revealed no literature that could be applied specifically to the research question of this paper.

This makes it challenging to draw conclusions from an evidence-based review, since the number of articles available in the literature is skewed by the tractability of modelling. This dilemma facing macroeconomic analysts is illustrated in the dual approach taken by the OECD. On the one hand, in their annual employment outlook (OECD, 2013) they routinely report on the 'output gap' as a measure of slack in the economy, and the degree to which it is out of equilibrium. The output gap as described below is a key concept underpinning Keynesian explanation of unemployment, indicating the extent to which governments have room for manoeuvre to provide additional stimulus to tackle unemployment without adverse economic impacts. On the other hand, the OECD's macroeconomic analysis of green jobs relies on equilibrium models which provide no detailed account of the output gap (OECD, 2012).

Nevertheless, the wider macroeconomic principles outlined in this section are important issues to bear in mind when interpreting the results derived from the narrower perspective of the 'green jobs' literature.

2.2.1 The 'Natural' Rate of Unemployment

Most of the discussion of unemployment in this report is relevant to conditions of recession, which in macroeconomic terms are periods when the economy is out of equilibrium due to some kind of economic shock.

However, it is important to recognise that even in periods when the economy is in equilibrium (i.e. times of so-called 'full employment'), there tends to be some level of unemployment, referred to as the 'natural' rate of unemployment. This occurs due to frictions and imperfections that are considered a normal part of the labour market. For example, the labour market is always in a state of flux because people move and change jobs, firms open and close, and it takes time for individuals to find the right job.

There is often a significant difference between countries, some of which may be cultural, some of which may be down to institutional differences, such the role of unions. This implies that there can be a role for policy in increasing labour market flexibility to reduce this 'natural' rate (e.g. through employment contract law, re-training programmes and other policies to address long-term unemployment), but these are not the kind of policy intervention relevant to the present discussion. Discussion of unemployment in the rest of this report refers to the periods of higher levels of unemployment, above the natural rate experienced during recessions. The policy mechanisms for addressing these tend to be of a different type, relating to stimulating additional economic activity.

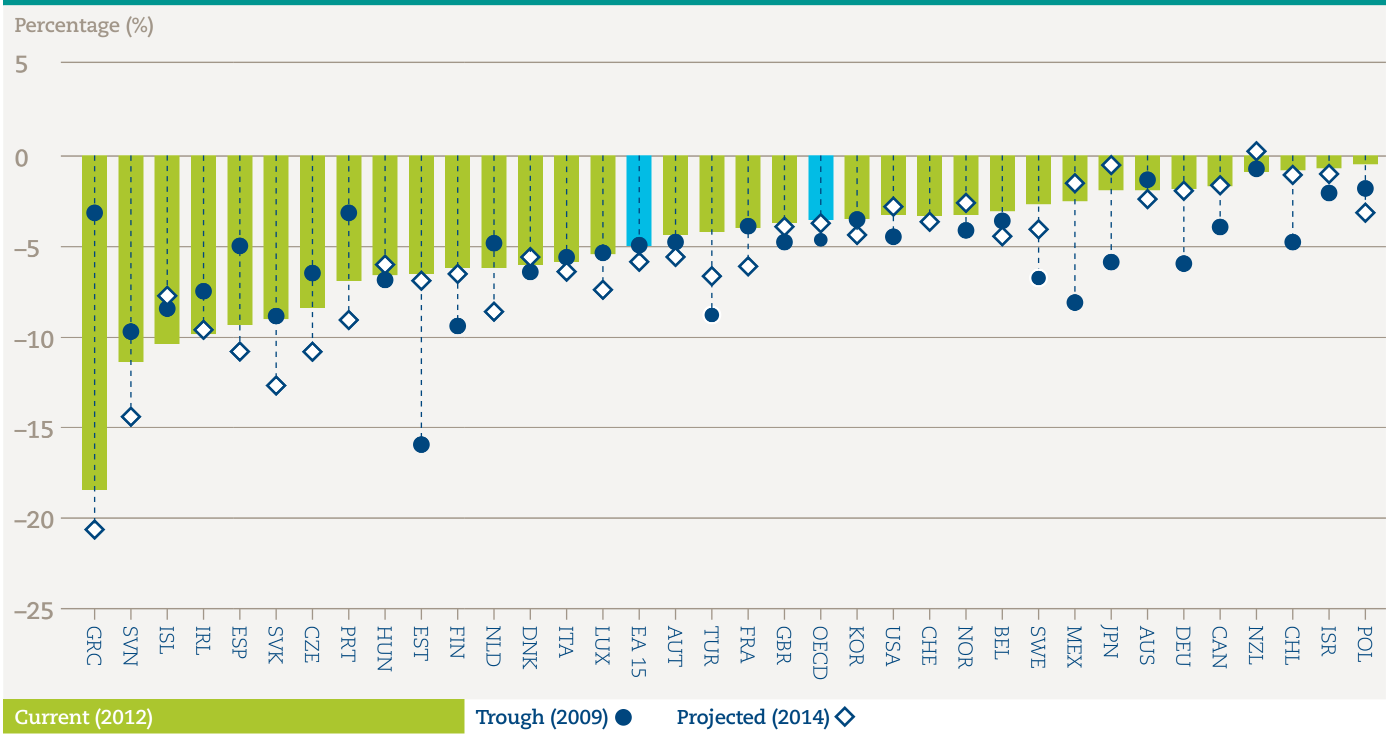
2.2.2 The Output Gap and Aggregate Demand

The frictions and imperfections described above also contribute to higher levels of unemployment as the labour market adjusts to a large shock since many more people and jobs will be affected during the onset of a recession. However, it has proved difficult to explain the empirical evidence of the depth and the duration of unemployment effects of recession purely through these kinds of microeconomic and behavioural effects, suggesting that other factors are also responsible.

The Keynesian tradition largely by-passes this discussion of the micro-economic causes of unemployment, and instead focusses on macroeconomic behaviour where large deviations from equilibrium are observed during periods of recession. Central to this analysis is the idea of an 'output gap' which is the difference between the total level of production in the economy and the production levels that would occur during periods of equilibrium or full employment. This gap opens up during periods of recession because shocks to the system knock demand for goods and services below their equilibrium levels, leaving human and physical capital under-utilised.

Despite some practical difficulties of measuring this output gap (and contentions regarding the lack of microeconomic foundations), it has become a mainstream tool for analysing both the need for and potential for policy intervention, for example, in the OECD Labour Market Outlook (Figure 4).

Figure 4: The Output Gap – OECD Labour Market Outlook 2013



Note: Percentage-points change in the output gap since the start of the global financial crisis (2008) in 2009 (trough of the output gap), 2012 (current output gap) and 2014 (projected output gap)

The idea of the output gap is important because it gives an indication of the space available to policy-makers to respond by stimulating demand and increase economic activity. Although economists differ regarding the degree to which market stimulus is an appropriate response to recessions, there is considerable empirical evidence that if there is an output gap, then policy-makers have more room for manoeuvre to intervene and create jobs.

At times of full employment, if there is no output gap, then application of economic stimulus by the government would tend to simply push up inflation, cancelling out any overall economic benefit. This is because if human and physical resources are fully deployed, then output cannot be increased. Herein lies some of the controversy surrounding the Keynesian diagnosis. Nearly all economists would agree that the output gap approach is an appropriate description over short timescales, and that equilibrium analysis is appropriate over long timescales. The argument tends to be about how short is 'short-term'. If the economy is assumed to adjust over periods of a year or two, the space for economic stimulus becomes very constrained. If the economy takes five years or more to adjust, there is plenty of time for the economic policy to have a material impact.

Underlying the Keynesian explanation of the output gap is the concept of 'aggregate demand', which defines the level of prices and output at which the goods and money markets are both in equilibrium. Aggregate demand consists of the demand for consumption (by private firms and individuals), investment, government spending on goods and services, and net exports. If the aggregate demand in the economy becomes suppressed due to a shock in either the goods or money markets, then demand can be increased again through either fiscal or monetary stimulus, as discussed in the next section.

2.2.3 Fiscal and Monetary Stimulus

Governments have two main policy levers they can use to generate economic stimulus; fiscal and monetary. Fiscal stimulus is an increase in government spending (either on goods and services or on investment) or a decrease in taxation levels which increases disposable income for individuals and firms. Fiscal stimulus directly increases aggregate demand in the economy because government spending, and consumption levels of individuals and firms, are all explicit components of aggregate demand. This increases economic activity, and would therefore be expected to directly increase employment levels.

Monetary policy acts indirectly by changing the supply of money in the economy which changes interest rates and returns on savings. Easing money supply reduces the yield on bonds and other investment assets, lowers interest rates, and increases the incentive to spend rather than save. This again leads to an increase in aggregate demand in the economy, simulating overall output and hence employment.

The choice of fiscal vs. monetary policy has different effects in terms of the composition of output. Government interventions often combine some aspects of both approaches in order to try to simultaneously control employment and inflation effects.

2.2.4 Multipliers, Interest rates, and Crowding Out

The 'multiplier' measures the size of the total economic impact relative to the size of the government stimulus. In the case of fiscal stimuli, the multiplier measures the number of £'s increase in total output for every £1 spent (or foregone in taxes) by the government. Governments typically aim for multipliers of significantly more than 1. This is feasible in the short-term because the £1 spent by government not only leads to a direct increase in output, but as a result leads to increased income of individuals and firms who in turn will tend to spend more. The size of this 'induced' spending effect depends in turn on the marginal propensity to consume (i.e. the share of any increase in income that will be spent on consumption rather than saving).

The impacts of fiscal and monetary stimuli (and therefore the size of the multiplier) are tempered by their impacts on interest rates. Expansionary fiscal policy creates increased demand for goods and services, which in turn raises demand for money in the money markets, pushing up interest rates. This in turn reduces the incentive for firms to invest. Since investment is one element of aggregate demand in the economy, this reduces the scale of the overall scale of the rise in income.

This interest rate effect is termed 'crowding out', since government expenditure effectively leads to a reduction in private investment. The extent of crowding out depends entirely on the extent to which increased demand in the money markets leads to higher interest rates, which in turn depends on the wider state of the economy. Under conditions of full employment, there can in principle be complete crowding out, whereby government spending has no effect on the equilibrium level of income since this is entirely offset by a reduction in private (mainly investment) spending. When the economy is below full employment, crowding out will be a matter of degree, with government spending leading to some increase in income and some increase in interest rates. In principle, crowding out can be offset by cancelling out the interest rate rises from fiscal policy by loosening monetary policy.

Macroeconomics tends to treat multipliers as a feature of the whole economy, measuring the responsiveness of the system as a whole. In the microeconomics literature assessed in this report, multipliers, whilst having the same general meaning, are often estimated from a bottom-up perspective. In that context, different policy interventions might be expected to have different multipliers. However, the use of multipliers typically implies some time dimension. Whilst government intervention may have a stimulus effect in the short-term, creating ripple-through effects when there is overall underutilisation of resources, in the long-term, governments will have to retract such support and pay back any debts acquired to finance the interventions. Over longer time horizons, the multipliers may therefore be significantly lower.

2.2.5 Business Cycles, Growth and Technology Development

Business cycles occur partly because private consumption tends to be pro-cyclical, i.e. spending during the good times, and retrenching during the bad. Governments can help iron out these cycles to some extent by pushing public expenditure in the opposite direction. Fiscal and monetary stimuli have a role to play during periods of recession, but can do more harm than good during periods of full employment. Good policy design is therefore a matter of timing, and estimating the expected duration and depth of a particular period of recession (i.e. the business cycle). This is far from an exact science, and lags in the effects of policy can exacerbate the difficulties.

Policies that last beyond the time horizon of the current business cycle therefore, in some sense, lock in the economy to a particular set of behaviours that go beyond their initial stimulus impacts. In these cases, it is important to assess the balance of costs and benefits to the economy in terms of the impact on growth potential. Neoclassical growth models typically attribute the key driver of growth for an economy in equilibrium to technological progress (plus population growth).

In general therefore, when thinking about the design of stimulus programmes, it makes sense to support technologies and projects that support technological progress in the long-term, because then if they have persistent effects in the economy beyond the timeframe of the direct stimulus effects, they should also help contribute to long-term growth.

In this longer-term context, labour intensity on its own is not economically advantageous, as it implies lower levels of labour productivity (economic output per worker). In the long-run, productivity matters more to long-term growth. In this context, the characteristics that matter are not how many jobs are created per unit of investment, but whether or not the investment contributes towards an economically efficient transition to the next expected equilibrium position in the business cycle. To address this adequately requires environmental externalities to be factored in to the assessment.

Modelling Methodologies[6]

3

6 This section draws on the Working Paper prepared for this project: 'Report on the evidence for net job creation from policy support for energy efficiency and renewable energy: An appraisal of multi-sectoral modelling techniques (Allan *et al*. 2012) available at www.ukerc.ac.uk/support/Low+Carbon+Jobs

3.1 Input-Output Models

3.1.1 Overview of IO method

Input-Output (IO) analysis requires the use of a set of IO accounts for an economy. These identify the monetary linkages both between production sectors in an economy and between production sectors and consumers of output (both domestic and non-domestic). The IO table gives a "snapshot" of the nature of production and consumption flows in an economy during a specific period of time, usually a year. A schematic of an IO table is shown in Figure 5. Column entries describe purchases, either from production sectors or of primary inputs. The row entries represent sales of products and primary inputs to production sectors and final demand categories. "Final demand categories" show purchases by households, government, capital formation, stocks, and exports of the outputs produced by each sector in the economy. The "Intermediate quadrant" shows the flows of spending between production sectors on intermediate inputs. "Primary inputs" will show purchases by local production sectors of non-domestically produced goods and services. These will include imports, taxes, subsidies, wage payments and payments to capital. The number of sectors (*N*) and final demand categories (*K*) can vary with the level of detail at which the table is constructed.

Figure 5: Schematic layout of an (analytical) Input-Output table

Sales → / Purchases ↓	Production sectors (n=1,…,N)	Final demand categories (k=1,…,K)	Gross output
Production sectors (n=1,…,N)	Intermediate quadrant	Final demand quadrant	Sectoral gross outputs
Primary inputs (including imports)	Primary Input quadrant	Final demand for purchase of primary inputs	Gross primary inputs
Gross Inputs	Sectoral gross inputs	Gross final demand inputs	

IO tables are quite data-intensive, so analysis often relies on tables constructed by governmental statistical agencies. These are often at national level, but are sometimes available at more localised levels. More recently, international or multi-regional input-output (MRIO) tables have been developed which enable analysis of cross-border environmental and employment issues. For a review of recent developments and applications of MRIO, see Wiedmann *et al.* (2011)

IO tables commonly serve two uses – "attribution" and "modelling". Attribution refers to the use of the IO accounts to assign responsibility for all output (and variables which can be linked to production, such as employment, value added or pollution) in the economy to final demand categories for the goods and services produced in the area.

In their second use, the inter-industry linkages detailed in the IO table can be used to model the economy-wide impact of new (exogenous) final demand disturbances. These disturbances might be either sector-specific – e.g. increased demand for the output of a particularly sector– or relate to changes in the levels of a final demand category. This is the context for most of the IO modelling used in the green jobs literature reviewed in this study.

The IO matrix can be manipulated to give the additional impact on economic activity (i.e. output) of a unit change in the final demand for that sector's output. This is referred to as that sector's "output multiplier", as it shows the impact on total activity of an initial change in demand. Multipliers use the inter-industry linkages provided by an IO table to quantify the aggregate "knock-on" effect of changes in demand for individual sectors (Miller and Blair, 2009).

The calculated "output multiplier" will be larger than one as total output will be higher by the unit increase[7] plus the additional activity in other sectors of the economy which are required to provide inputs to the now expanded sector (and those sectors which have expanded to produce inputs to the sectors which are linked to the sector which saw the initial increase in demand). Through this "rippling" process, the sectoral multiplier will reveal the difference between the initial demand disturbance and the aggregate effect.

7 We refer to increase, but the same method would apply if the change in final demand for sector's outputs was negative.

IO analysts might use "Type 1" and "Type 2" multipliers, which make different assumptions about the treatment of additional wage income and consumption spending. Under Type 1, the multiplier takes account of the interlinkages between sectors to calculate the total effect on sectors' outputs (and hence inputs) of an increase in final demand for a specific sector. The difference between the Type 1 multiplier and the "direct" effect (i.e. the initial stimulus) is termed the "indirect" effect. Any increase in output, and employment, observed under a Type 1 analysis assumes that the increased level of wage income does not act as a further demand stimulus to activity. The Type 1 process is sometimes referred to as the "open" model (Miller and Blair, 2009).

With Type 2, the household sector is included alongside the production sectors. This requires the extension of the matrix with an additional row and column relating to the household sector. Each labour expenditure row element is the relevant sector's purchases of labour divided by the sector's gross output, while column elements are households purchases of goods and services divided by total wage income. This procedure is referred to as "closing" the model with respect to households, usually shortened to refer to a "closed" model. Under this setup, increased wage incomes are retained in the economy through increased household consumption, and so Type 2 multipliers will be greater than Type 1. The difference between Type 2 and Type 1 multipliers is termed the "induced" effect.

The impact on other variables – i.e. employment, value added, and income – can be straightforwardly estimated through the calculation and use of alternative "multipliers". As Miller and Blair (2009) note, "an analyst is more likely to be concerned with the economic impacts of new final demand as measured by jobs created, increased household earnings, value added generated, etc., rather than simply gross output by sector". Sectoral "employment-employment multipliers", for example, reveal the impact on (aggregate) employment to changes in (direct) employment in a specific sector. An employment-employment multiplier of 3.0 for instance, would mean that five new jobs created in a particular sector could be expected to create fifteen jobs across the economy.

3.1.2 Modelling new activities in IO

Most of the literature reviewed in this study used IO frameworks for evaluating the economic impacts of new renewable energy developments. One approach is to estimate the (annual) operational expenditures associated with a new energy technology, and input these as the disturbance to final demands for specific sectors in the IO table. Care should be taken to ensure that the expenditures are as closely matched as possible to the appropriate activity which could see an increase in demand for its output. It is important that the results from the construction phase of the project be identified separately from those for the annual expenditures of the project. Once the annual expenditures related to a particular development have been identified, the IO table can be used to calculate the impact on annual employment resulting from these expenditures. This would give the change in employment consistent with the new equilibrium level of output, where final demand is now permanently higher than before.

A second approach is to incorporate the new renewable energy development into the IO table for the economy under consideration by specifying its (annual, if the IO table is for a year) forward and backward linkages explicitly, and "adding" a new sector to the economy which represents the new development. To include the new industry in the technical coefficient matrix means that a new row and column describing the pattern of sales and purchases by the new sector must be identified.

This approach typically only focuses on the operational phase of the energy development. The results obtained would then be the new level of economic activity – including employment – which would be consistent with the operation of the new renewable energy facility. The linkages between the development and the economy would therefore be crucial for the modelled result, as would the potential for the new activity to displace existing economic activity (Allan, 2013).

The impact of the construction phase could be estimated separately using IO. This would typically involve using the sector specific expenditures and appropriate multipliers to estimate the system-wide impacts of these expenditures. One should be careful when comparing the economic impact from the operational phase of a project to the construction phase. The impact of the operational phase would be the recurring impact on the economy under consideration in each year of the project, while the construction phase is typically much shorter.

An additional benefit of IO models for examining the operational, as well as construction, phases of renewables is that the modeller must make explicit the assumptions about the domestic supply chain, i.e. linkages, of the technology. For nascent technologies these links may be difficult to construct, but this adds transparency to the analysis.

IO models typically assume a "demand-driven" system, in which supply is passive. This would mean that there would be no assumed displacement of existing activity as a result of new activity moving to the region (typical of an 'economic stimulus' perspective). This may be a reasonable assumption in some areas or time periods, e.g. with high unemployment placing limited pressure on wage rates following a demand-shock. However, this assumption is certainly not always appropriate. Such constraints could be accommodated within a CGE framework, as will be discussed later.

3.1.3 Electricity sector in IO

The impact of changes in final demand for the output of existing sectors is relatively straightforward to model. For the analysis of RE however, the sectoral classification typically fails to separately identify a single sector called "renewable energy". The generation of electricity from renewable sources, for instance, will typically be part of (and so combined with) the rest of the electricity sector. Further, this electricity sector includes generation of electricity as part of its activities – transmission, distribution and supply of electricity are also included within this sector. Other activities which relate to renewable energy will typically be part of existing sectors in the IO accounts, for example, wire and cable production, surveying or manufacturing of generators.

Where the IO tables are constructed with a single electricity sector, this relates to all activities – i.e. generation, transmission, distribution and supply. The single multiplier for the "Electricity" sector masks the potential for there to be quite different linkages between electricity generation technologies and the economy, and so potentially significant different multipliers. Allan *et al*. (2007a) and others (Wing, 2008) have identified that bottom-up surveys of generation technologies can allow these to be "extracted" from the non-generation elements of the electricity sector. When these differences in inputs to each generation technology are accounted for, there can be quite significant differences in the estimated multipliers for generation technologies.

3.1.4 Social Accounting Matrix (SAM) applications

A more detailed set of accounts than an IO table, called a Social Accounting Matrix (SAM), can be used to examine the economic impacts of disturbances in an economy from a wider perspective, although both approaches share similarities such as linearity. SAM analysis, as with IO, begins with a set of accounts describing the nature of production in a particular period, however, unlike IO, a SAM offers a complete picture of all incomes and expenditures within that area. An IO table, for example, has particular focus on incomes related to production activities, but does not include incomes and expenditures which are not related to production in that period. For instance, the wage payments given in an IO table are only those related to production in that same period. Although wage income will typically be the largest element of household income for many households, other forms of income – not linked to production – will also be received in each period. These could include public or private pensions, other benefits such as unemployment insurance, or receipts of income from abroad.

Taking account of all incomes, and not just those linked to production activities, can also be done alongside disaggregation of the elements of final demand to get a fuller picture of the incomes and expenditures of particular categories. This has been particularly a focus for the analysis of the economic impacts of demographic or poverty-related policies as the household final demand category might be disaggregated by age of household or income of household. SAMs have a history of being used to evaluate the distributional impacts of policies on poverty and household groups, and so would provide a dataset perhaps more suited to exploring issues such as fuel poverty, for example, than an IO system.

Although IO studies are more common some recent work has used SAMs to examine the impact of renewable energy technologies (Swenson and Eathington, 2006; Wing, 2008; Allan, 2013). These studies acknowledge that using IO tables to quantify the impact on activity could be misleading, as these focus exclusively on intermediate inputs and employment linkages between technologies and the economy. As described in section 3.1.1, analysis using Type 1 multipliers captures inter-industry linkages, and analysis using Type 2 multipliers extends this to capture wage payments. Further "closing" the IO model with respect to capital formation has been done in the past, but is much less common. SAM analysis can show significant impacts on economic activity when ownership profits are retained (and spent) within that same economy.

3.1.5 Strengths and weaknesses of IO for modelling employment effects

There are three important assumptions underlying the use of "demand-driven" IO analysis for modelling:

- Fixed technical coefficients and constant returns to scale
- Demand is exogenous
- Entirely passive supply side

The first assumption implies that the inputs used by a sector increase in proportion to any change in the output of that sector. For example, if demand for a particular sector's output increases by 10%, then that sectors demands for each of its inputs (from other intermediate sectors and primary inputs) also increase by 10%. The sector is taken to be characterised by fixed technical coefficients in production, meaning that industries cannot substitute inputs in production, but always purchase inputs in the same proportion as per its column in the IO table.

The second assumption requires that any economic disturbance be translated into a change in demand, and that this is exogenous. This might be a changed demand for a specific sectors' output, or a changed level of demand for a specific category of (final demand) expenditure. In estimating the employment impacts of changes in exogenous demand, it is crucial that the disturbance is correctly introduced, and takes account of any displaced economic activity, for example.

The final assumption is perhaps central in "demand-driven" IO and SAM analysis. Where demand for a sector's output increases, the demand for inputs to that sector's production also increase, raising the demands for all production sectors to expand through their links to the directly stimulated sector. In conventional IO modelling treatment, at no point in this "rippling" of additional production is there assumed to be anything preventing the output of any sector adjusting to satisfy the increased demand. There must therefore be no constraints on the ability of sectors to source intermediate or primary inputs (e.g. labour). A further implication of this assumption is that there is no inherent "switching" of resources between sectors in the face of increased demand: no sectors are required to contract in order that other sectors can expand. That is to say, for all demand increases, these can be accommodated through the expansion of supply at the existing prices, with no crowding out effects. This is consistent with a region or nation which has extensive underutilisation of resources, such as significant underemployment of labour and excess productive capacity. Similarly, in a region which was able to attract labour and capital resources through migration and investment respectively, such supply constraints could be non-binding in the long-run (McGregor *et al.*, 1996).

It is the simplicity of IO that has led to its being the most widely used method of assessing employment impacts (Berck and Hoffman, 2002). It has been acknowledged, however, that the three assumptions outlined above can make it unsuitable for modelling policies in which relative prices change within an economy (as these are not modelled). Consequently, linear models would not be expected to overstate regional effects in applications to a "small economy with policies that do not affect relative prices" (Berck and Hoffman, 2002). When relative prices are expected to be changed from their initial levels, it would be beneficial to consider a (more complex) modelling approach such as CGE.

3.2 Computable General Equilibrium (CGE) analysis

A CGE model is an analytically consistent mathematical representation of an economy. The basic structure is straightforward – it comprises a detailed database of actual economy-wide data which captures the interdependencies across all sectors in the economy at a particular point in time, and a set of equations describing model variables. These equations tend to be neoclassical in spirit: households maximise utility, subject to a budget constraint, and firms maximise profits (minimise costs). This gives rise to demand and supply functions, derived in accordance with standard consumption and production theories.

Most CGE models tend to be static, in that they do not incorporate a time element, and model the reactions of the economy at only one point in time. A recent area of progress in CGE modelling relates to the incorporation of "recursive" dynamic properties into the model structure[8].

A "typical" CGE framework tends to have:

Two factors of production (labour, which may be disaggregated by skill level, and capital); have a limited number of commodities; and model inter-industry linkages based on an IO table or SAM database. In addition, the assumption of 'constant returns to scale'[9] for production technologies is often used to facilitate an equilibrium concept upon which to base the analysis.

The models are solved computationally, with an equilibrium being characterised by a set of prices and level of production across all sectors, such that demand equals supply for all commodities simultaneously[10]. The framework is used to estimate how an economy might react to changes in policy or other exogenous influences, and the counterfactual solutions provide quantitative estimates of the impact of specific policies or effects on the allocation of resources and the relative price of goods and factors.

The number of endogenous variables for which the CGE model can obtain a solution is constrained by the number of independent equations. Accordingly, this requires that a number of model variables are specified as exogenous, thereby determining the model closure. This choice reflects the (primarily macroeconomic) assumptions within which the policy analysis is set, and therefore depends on the nature of the issue being addressed.

Although a 'classic' CGE model yields a full-employment equilibrium with market clearing prices, many researchers impose alternative macroeconomic closures on the framework. These exemplify some necessarily ad hoc assumptions concerning the characteristics of agents or markets, so as to impose more realistic macroeconomic behaviour on the neoclassical framework. These features include, for example, wage and price rigidities, partial adjustment mechanisms and non-market clearing equilibrium.

8 By static, we mean "comparative static" in that results compare one equilibrium to the next. In contrast, dynamic models explicitly incorporate a time element into the framework (for example by making model agents forward-looking). In doing so, they can be used to model changes over time, and to describe the process of model adjustment over time. For such multi-period dynamic models, all time periods must be solved simultaneously (rather than one period at a time), making the mathematical solution techniques more complex than for static models. Accordingly, there are fewer examples of fully dynamic CGE models in the literature.

9 Constant returns to scale implies that a change in all production inputs by x units leads to a change in production output by x units.

10 Underlying the CGE methodology is the Walrasian general equilibrium structure, which is expressed in mathematical terms as a system of simultaneous equations representing market equilibrium conditions, where an equilibrium is characterised by a set of prices and levels of production in each industry such that demand equals supply for all commodities simultaneously.

In particular, various model closures are often used to represent different assumptions about the operation of the labour market. To represent an assumption of involuntary unemployment, for example, the researcher may set employment as endogenous and exogenously fix wages at an above-equilibrium rate. Alternatively, a full employment, perfectly flexible labour market assumption may be represented by a model closure that sets wages as endogenous and employment as exogenous so as to reflect the fixed labour supply of the economy.

Once the model is fully specified and parameterised, it can be used to simulate the effect of a policy shock or an exogenous change in economic conditions by specifying new values for policy instrument(s) or economic variable(s) of interest. The simulation outputs are used to analyse the effects of these exogenous changes on the endogenous variables of the model – consumption, production, prices, exports, employment, and/or the impact on welfare, depending on the model specification (Greenaway *et al.*, 1993)[11]. The model is solved for a unique set of prices that identifies a new market equilibrium for each policy, allowing for direct comparison amongst policy alternatives.

3.2.1 Dynamic CGE frameworks

Advances in computing software, together with the appeal of CGE modelling as a tool for policy analysis, has meant that CGE modelling has been a productive area of research in recent years. Until relatively recently, CGE models tended to be comparatively static in nature. An important area of progress in CGE modelling relates to the incorporation of dynamic properties into the model structure (Harrison *et al.*, 2000), allowing for growth to be endogenised. In most cases, the dynamic properties are recursive in nature. This involves the linking of a sequence of single-period equilibria through stock-flow relationships. The computed equilibria vary over time as the value for the model's stock variables adjust. Flows in previous time periods (for example investment, interregional migration, and government borrowings) have an effect on values of endogenous variables computed in each period via their influence on the values for the stock variables in each period (for example capital, population and government debt). In contrast, full multi-period dynamic CGE models explicitly incorporate agents' forward looking expectations, and this requires all periods to be solved simultaneously. For their part, firms maximise their present values, and the existence of capital stock adjustment costs smoothes the response of capital stocks to shocks.

By endogenising potentially important sources of economic growth, these models may capture crucial aspects of a policy change or exogenous shock that a static simulation excludes. However, dynamic models, being more theoretically complex, are more difficult to solve, limiting their impact to date in the literature on the topic of green jobs.

3.2.2 Strengths and weaknesses of CGE modelling

A key strength of the CGE modelling approach relates to its microfoundations. In CGE models, the optimising assumptions associated with general equilibrium modelling are typically preserved, which therefore allows for an analysis of the effects of a policy or exogenous change at the micro level. The method involves explicitly modelling the behaviour of producers and consumers, so that behavioural assumptions are clearly stated, and this formal structure aids in the comprehension and transparency of the model.

The model structure allows alternative model specifications to be compared and contrasted, allowing for a full examination of the effects of different functional forms on the model simulation results (Cox and Harris, 1985; Greenaway *et al.*, 1993). Further, CGE is particularly useful when examining the impact of novel policies or new sectors, to which econometric methods would not be applicable.

The ability to incorporate interdependencies and feedback effects is another important feature of the CGE approach. The regional impact of changes in policies or exogenous shocks may be significantly different from the aggregate effects (Nijkamp *et al.*, 1986; Miller and Blair, 2009). Furthermore, most policy changes are likely to have impacts on employment and other economic measures beyond only the target variable or sector. Such economy-wide, spatially-disaggregated effects are difficult to capture in anything other than a general equilibrium framework.

The degree of aggregation of the model will be dependent upon the policy question at hand, but a further useful aspect of the CGE framework is that, should a sector or subsector be of particular interest, it is relatively straightforward to disaggregate the data set upon which the model is based[12]. This means that the analyst can identify how the gains and losses on employment are distributed among sub-sectors, regions or employment groups (or groups of society/social class of household, depending on the data used to specify the model). Since

11 CGE models are also often used to measure the impact of policy changes or exogenous shocks on economic welfare, using Hicksian compensating or equivalent variations measures, for example. Compensating variation is an estimate of the amount of money a consumer would be willing to accept in order to be compensated for a change in some circumstance (such as a change in prices, availability of goods or services, landscape quality etc), such that their overall utility is unaffected. Equivalent variation measures the amount of money a consumer would be willing pay in order to avoid a change in some circumstance.

12 However, this is subject to data availability and, in the case of interregional models in particular, a degree of aggregation is often required in order to ensure data consistency.

all policy effects will have distributional consequences across the economy – whether sectoral, spatial or welfare-related – this feature helps inform policy assessment[13].

The flexibility inherent in a CGE framework makes it particularly useful for evaluating the response of the economy to a range of policy shocks. The effects of policy 'packages' on employment, where there is a change to more than one exogenous variable, can also be considered and compared. Alternatively, where there is uncertainty surrounding some aspect of the economy, such as the true characteristics of the operation of regional labour markets, for example, various configurations can be incorporated into the framework, and the consequences for model results on employment and the wider economy can be analysed. CGE models can validate or refute¬ policy-makers' presentiments about the likely effects of a policy, and can emphasise unanticipated outcomes. They help to demonstrate the means by which a policy works its way through the economy and can highlight anomalies between short-term and long-term effects. Furthermore, they encourage a more inclusive approach to policy analysis by helping to develop a wider perspective about the impacts of a policy or exogenous shock on employment and the economy as a whole.

As with all techniques in applied economics there are limitations associated with the CGE methodology, though modellers can adopt a number of approaches that attempt to minimise these.

Although, theoretically, a CGE model can accommodate any functional form, modellers typically use only functional forms that are relatively straightforward and tractable to use. This often means CES (constant elasticity of substitution) or Cobb-Douglas forms, for example, being specified in the model. Whilst there is a significant volume of literature to suggest that CES functional forms fit production and consumption data relatively well and perform well in such econometric studies (Arrow *et al*., 1961; Uzawa, 1962; McFadden, 1963), in practice, agents' behaviour may not actually be consistent with these. In general, there is a lack of empirical validation of CGE models, leading to uncertainty over whether they accurately represent either the comparative statics or dynamics of the economy.

Similarly, modellers face various constraints relating to the numerical specification of the model. The model is calibrated to a benchmark year, which is assumed to be in equilibrium, and the calibration practice is justified on the grounds that the values which result from the calibration process are consistent with the equilibrium. However, the assumption of an equilibrium may not necessarily hold in practice. In particular, assumptions of equilibrium do not match the conditions of an 'output gap' which underpin the relevance of the concept of job creation.

Overall, although CGE techniques provide invaluable guidance for policy-making and enable analysts to consider the consequence of policy changes on employment, the simplifying assumptions that are necessarily imposed, together with various data constraints, mean that the outcomes of CGE models must be interpreted as 'insights' rather than absolute truths.

3.3 Macroeconometric models

Macroeconometric models encompass a wide range of probability models for macroeconomic time series analysis and estimation and inference procedures. The models are used to address many different issues, including examining the impacts of policy measures; understanding propagation of policy shocks; or examining the determinants of business cycle fluctuations or economic growth.

Popular modern macroeconometric models which are currently used for policy analysis include dynamic stochastic general equilibrium (DSGE) models. Early DSGE models were developed to study how real shocks to the economy might cause business cycle fluctuations (Kydland and Prescott, 1982). They are closely related to CGE models in terms of specification and computation: they are founded on microeconomic assumptions about tastes, technology, constrained optimisation and general equilibrium. In contrast to CGE models, however, agent maximisation occurs within a stochastic (i.e. randomly-determined) environment, rather than a deterministic one. Recent DSGE models have become more complex, with increased structural shocks, real and monetary frictions and adaptive expectations being considered within the framework for added realism and improved empirical fit to the data.

Dynamic optimisation and optimal control theory models also have their uses in policy analysis: they are able to trace the dynamics of the economy over time, and aid the selection of the optimal time path of policy changes according to specified criteria. Macro-based models of this type, however, are generally not capable of modelling distributional effects, whereas micro-based models in this category tend to rely on partial equilibrium principles, precluding their ability to model the economy-wide interlinkages and feedback effects that are the stronghold of CGE models.

Owing to their large data requirements and complex solution methods of optimal control and DSGE models, we do not see any examples in the literature of these models being used to estimate the impacts on employment or the economy of renewable policy support mechanisms.

13 In principle the CGE construct can model welfare changes explicitly through the use of measures such as compensating variation and equivalent variation, so as to consider the net welfare benefits of alternative policy reforms within a framework with solid theoretical foundations.

Vector autoregression (VAR) models have been used to econometrically estimate the relationships between the energy market (including renewable energy) and the macro economy. VAR models are statistical models used to identify whether there are interdependencies between multiple time series and, where relationships do exist, to measure their extent. VAR models are not necessarily macroeconometric, since they do not explicitly model all parts of the economy.

A different type of macroeconometric framework used for analysing the economic impacts of renewable energy policy-making is the MDM_E3 model (and its variants), developed and used exclusively by the consultancy firm Cambridge Econometrics. This model is distinct from the purely econometric models described above. Cambridge Econometrics describes the framework as macroeconometric, but strictly speaking, it is an amalgamated IO model. The IO framework is based on a set of input-output coefficients which are updated with econometric time series relationships.

3.3.1 Strengths and weaknesses of macroeconometric modelling

In some regards, CGE modelling can be seen as complementary to macroeconometric models, in the sense that some of the weaknesses of the CGE approach are the strengths of these other approaches and vice versa. Macroeconometric models are able to explain the impact of a change in economic policy on aggregate variables in an economy over time. They have a firm basis in economic theory, and, unlike many CGE models, they are typically adept at incorporating detailed dynamic characteristics of the economy such as expectations, growth, capital accumulation and resource depletion. In addition, they are able to embrace notions of market disequilibrium, and monetary variables, for which CGE models are also typically less advanced in their treatment.

Nevertheless, macroeconometric models often have insufficient detail of the microeconomic structure of the economy. The production, investment and consumption functions that macroeconometric models are based on may not be a satisfactory reflection of the microeconomic structure of the economy. Furthermore, macroeconometric models tend to be lacking in their ability to provide sufficient detail on the distributional and efficiency effects of exogenous changes, which can pose limitations in terms of estimating sectoral employment impacts following precise policy changes. These two limitations of macroeconometric models are accepted as strengths of CGE modelling.

Macroeconometric modelling, like CGE modelling, is also constrained with regards to the adequacy and availability of data, and for macroeconometric modelling, particular concerns relate to the time consistency of the data being used and the ability to model structural shifts over time. In fact, one of the key advantages of macroeconometric modelling – the ability to reliably estimate parameter values from time series data – constrains its use for the purpose of analysing the employment effects of energy policy support, since insufficient time series data exist, particularly at the regional level but also at the national level, to be able to fully estimate a sufficiently-detailed multi-sectoral macroeconometric model of the UK economy.

The complexity of DSGE models means that they are difficult to solve and analyse. Accordingly, they tend to abstract from sectoral and regional detail and incorporate fewer variables, making them less useful for the type of policy analysis of job creation impacts of energy policy, for example, reflected in the fact that no studies of this nature were revealed as part of this literature review. They are more appropriate for examining the dynamics of the aggregate economy, and have been used extensively for monetary policy analysis.

Comparative Analysis of Job Estimates from the Literature

4

4.1 Methodology

4.1.1 Selection of papers

Of the eighty four publications reviewed (listed in the Appendix), fifty publications provided data in suitable detail that could be extracted to compare employment impacts of different types of electricity generation technology. This section presents the synthesis of this comparative analysis.

Thirty four papers were excluded from the quantitative analysis for one or more of the following reasons (numerical references relate to the paper index number in the Appendix table):

- **Insufficient quantitative detail,** or based on data that was duplicated in other papers by the same author included in this review (2, 10 , 23, 24, 29, 54, 62, 68, 69, 72, 73).
- **Technologies outside the scope,** such as nuclear (37), hydrogen (61, 82) and biofuels (12, 17, 25, 29, 56, 74, 77)
- **Focus on generalised climate policy,** without enough detail to distinguish between RE, EE and wider instruments such as energy and carbon pricing (7, 9, 21, 26)
- **Jobs figures insufficiently well-defined** to be able to distinguish between short-term job-years (e.g. construction) and jobs created over the lifetime of the generation plant (e.g. operation & maintenance), to allow total job impacts to be determined (8, 15, 16, 48, 66)
- **RE or EE investment not well-specified,** with insufficient information about either the investment costs involved or the capacity or scale of the plant being invested in (6, 12, 14, 45, 84)

In most cases, the papers which provided suitable data were based on case studies, surveys or input-output models. Some of the papers based on CGE or other econometric analysis provide relevant evidence for this review, but could not be incorporated into the comparative analysis because data was presented in a way that could not be normalised in the same way (9, 14, 45, 84). Since there are relatively few of these papers, a separate discussion of each of them is given in Section 4.5.

4.1.2 Gross and Net Employment Impacts

The research question of this report is concerned with assessing the net employment impacts of RE and EE investments. However, the majority of the publications reviewed provided only gross jobs impacts, with only twenty publications providing net impacts (3, 5, 11, 25, 31, 33, 34, 40, 41, 44, 46, 52, 55, 56, 58, 59, 70, 77, 78, 80).

Rather than rejecting publications that focussed on gross employment, it was decided to gather this information, since several publications provided data on gross jobs from coal- and gas-fired power generation. Approximate estimates of net job impacts can then be derived by comparing gross jobs estimates between RE/EE versus fossil fuel. This comparison only provides an approximate indication of net impacts for a number of reasons:

- There are only six publications which include data on gross jobs for coal and gas generation (3, 27, 31, 63, 75, 79), so the sample size of the fossil fuel comparator is rather small. This small sample size opens up the problem of methodological inconsistencies when comparing job estimates between different publications, though it is not clear that this produces a bias in any particular direction.
- Comparing RE with thermal generation on a GWh produced basis is not an exact like-for-like comparison (especially for wind and solar) because the intermittency of these sources means that provision may be needed either in terms of additional back-up capacity or additional interconnection or storage, which tend not to be included in the gross jobs estimates. Bottom-up surveys of the jobs (and investment) impacts of individual RE projects will therefore tend to exclude some positive gross employment impacts at the system-wide level.
- Most of the studies of gross job impacts do not take into account the effect of RE on the price of electricity, and the potential negative impacts this can have on employment due to reductions in disposable income of households. Such effects tend to be addressed in macroeconomic studies, evidence from which is assessed in Section 4.5.

Given that both positive and negative effects may be excluded, it is not obvious *a priori* that there are biases in any particular direction. This suggests that the analysis of gross job impacts can be treated as a rough-and-ready comparator between RE and fossil fuels, as presented in Section 4.2.

In Section 4.3, results are presented from publications which report net job impacts. In these papers, the job impacts of RE or EE investments have already been netted off against a baseline or counterfactual, usually a fossil-fuel related investment. For these publications, the problems noted above of inconsistencies in methodological approach do not apply. However, the degree to which authors address system-wide intermittency impacts of RE and the price impacts is often not made clear, and there is a tendency to omit these wider effects in the input-output models on which most of these results are based. The net jobs estimates should therefore also be regarded with some caution, though again, it is not clear *a priori* that there is a bias in any particular direction.

4.1.3 Calculating Employment Factors

The main purpose of this part of the review was to provide a quantitative comparison between publications' estimates of the extent to which employment is affected by investment in different types of energy project. This requires calculation of an indicator of the number of jobs created per unit size of project in order to normalise results to a common scale. As noted in Section 2.1.5, there are various choices to be made about both the numerator and denominator of such an indicator.

In this review, each job is taken to represent a FTE job which lasts for the anticipated duration of the plant in question. Jobs related to the ongoing operation and maintenance (O&M) phase of the project tend to be reported on this basis anyway, so no adjustment is necessary. Jobs relating to the manufacturing and construction phase tend to be reported in job-years equivalent. In order to convert to the same scale as O&M jobs, these need to be divided by the lifetime of the project. Where data on project lifetimes was not reported in the publications, a common value was applied for each type of plant taken from (EC, 2008) as follows:

Technology	Plant Life (years)
Wind: On and Off-shore	20
Solar: Photovoltaics (PV)	25
Solar: Concentrated Solar Power (CSP)	40
Biomass	30
Hydro-electricity	50
Gas: Combined Cycle Gas Turbine (CCGT)	25
Coal	40

This allows estimates of temporary job-years to be converted to lifetime job equivalents, and added to the O&M phase jobs to give a total job impact.

The choice of denominator was determined by the approach taken in each individual publication. One option was to use financial indicators, but publications tended to use quite a wide variety of different financial indicators, or were unclear about exactly what was included. The approach taken in this review was to only include financial information if it specifically related to the capital cost of the investments being assessed. This was the case in thirteen publications (17, 18, 25, 32, 33, 36, 41, 44, 51, 55, 63, 64, 80), allowing an indicator of jobs/£m invested to be calculated. In each case, monetary data was converted and inflated to pounds sterling (GPB) in 2010. Office of National Statistics and Bank of England data were used to convert and inflate currency.

The second option for the denominator was to take information about the size of investments from the physical scale of the plant. Most papers provided information in terms of the maximum rated capacity of plant (MW), whilst some papers provided data in terms of electricity produced (GWh). In order to provide a comparison between papers, and specifically in order to allow a comparison of the generation potential of plant on a roughly like-for-like basis, all plant size information was converted to annual electricity generation in GWh. This required assumptions to be made about the average availability or capacity factor for each technology. Where these were not stated in the publications, the following general assumptions were made:

Technology	Average annual capacity factor
Wind (Onshore)	30%
Wind (Offshore)	35%
Solar PV	11%
Solar CSP	30%
Biomass	80%

EE investments were also expressed in terms of the amount of electricity saved, giving an employment indicator of jobs/GWh saved that could be directly compared with the jobs/GWh produced for the RE and fossil-fired generation options.

4.2 Gross Jobs Summary

The gross number of jobs created per unit of electricity generated is shown in Figure 6 for different generation technologies. These figures show the range and average from all publications which provide data in each particular category. Comparisons between categories therefore involve comparisons between different sets of publications. For example, the direct (D), indirect (DI) and induced (DII) jobs in Figure 6 follows the availability of this breakdown in the literature. Each publications that estimated all three of these job types followed the expected pattern that DII > DI > D. However, because not all publications provided estimates of all three types, comparisons across these types in Figure 6 do not necessarily follow this expected pattern because they aggregate different data sets.

Figure 6 suggests that the literature supports a tentative conclusion that in general, RE and EE investments are more job-intensive than investment in coal- or gas-fired power generation. Whilst the data is not robust enough to support a detailed statistical analysis, the chart suggests that this positive effect could be of the order of magnitude of 0.5 job/GWh. The average for fossil fuels from these figures is about 0.15 jobs/GWh (coal 0.15, gas 0.12, CCS 0.18), the average across all RE is 0.65 jobs/GWh, and the average across all RE and EE is 0.80 jobs/GWh.

Figure 6: Gross jobs per annual GWh generated[14] (number of studies in brackets)

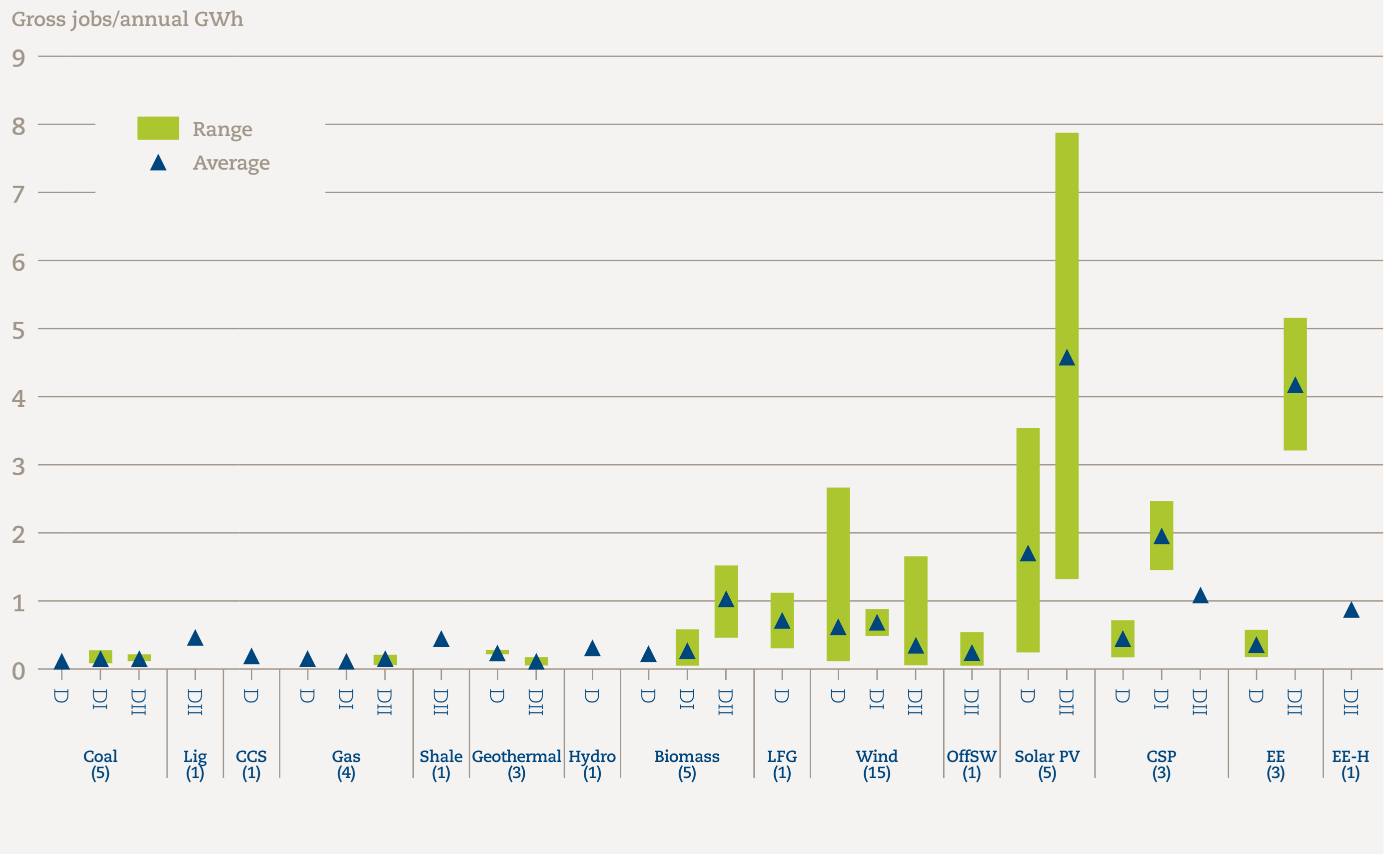


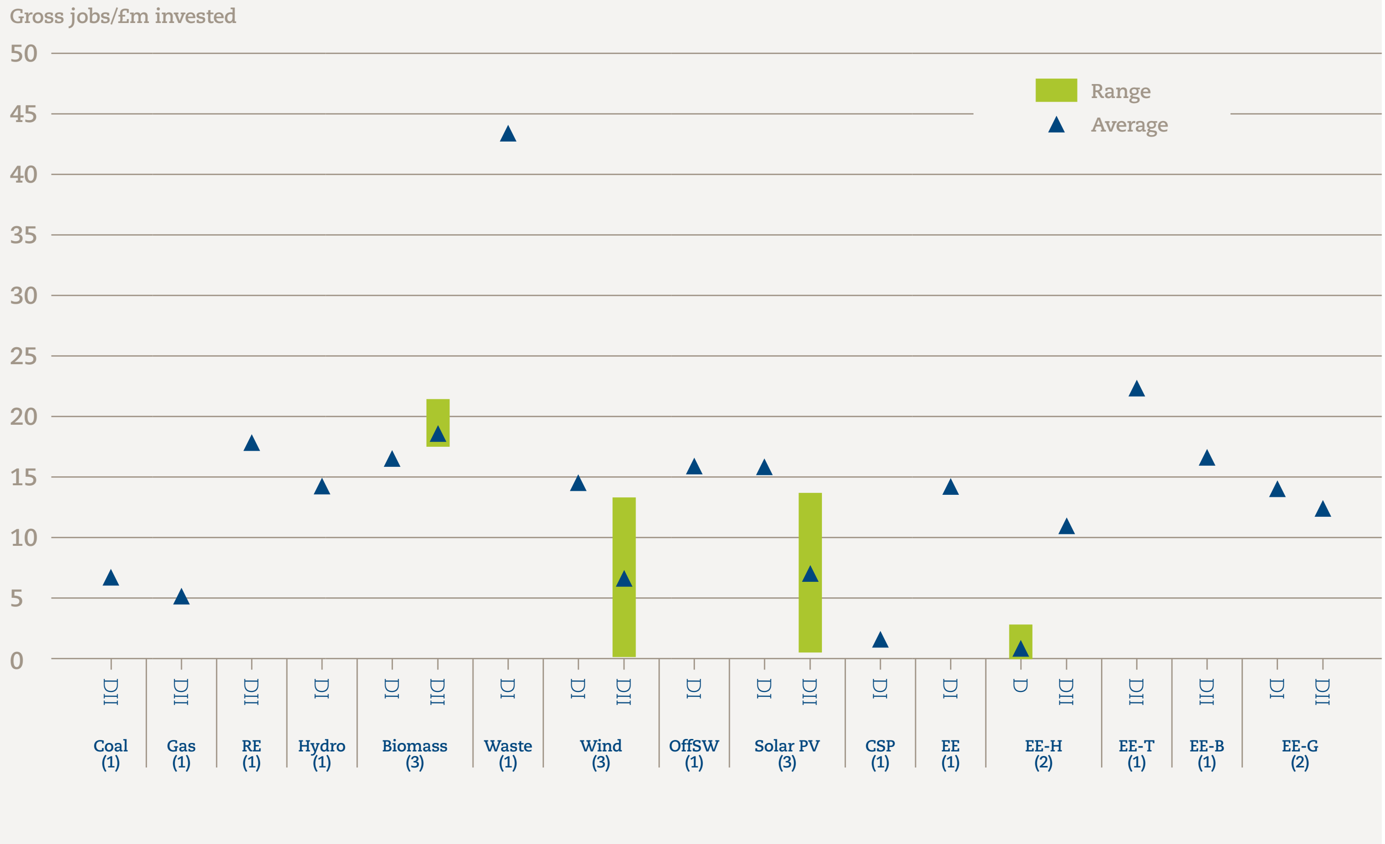
Figure 6 also suggests some interesting variations between different types of RE. For example, geothermal and hydro plant appear to be less job-intensive than other RE and EE options, whilst solar technologies appear to be more job-intensive than wind. The publications provide a large range of estimates for the gross job impacts for EE, reflecting the relatively wide range of applications included in this category. Further details for each technology showing the estimates of individual publications is presented in Section 4.4.

Figure 7 shows the employment impacts using a financial indicator, in terms of jobs/£m invested. As discussed in 2.1.5, a financial indicator may be more relevant when considering the effectiveness of stimulus packages for job creation in different sectors.

This metric tends to put fossil-fired generation sources in a more positive light, since they tend to be a cheaper source of electricity. This leads to a re-balancing of the chart in Figure 7 compared to Figure 6 (although note again that the two charts are not aggregating the same set of literature, which will account for some of the differences).

14 The following abbreviations key is used for charts in this chapter - D: direct jobs. DI: indirect jobs. DII: induced jobs. CCS: carbon capture and storage. LFG: land-fill gas. OffSW: offshore wind. CSP: concentrated solar power. Hyd: Hydro. Bio: Bio energy. Geo: Geothermal energy. PV: Solar photovoltaic. RE: general unspecified renewable energy. EE: energy efficiency. EE-H: energy efficiency in households. EE-T: energy efficiency in transport. EE-B: energy efficiency in buildings. EE-G energy efficiency in the electricity grid (including smart grid). EE-I: energy efficiency in industry. IO: Input-output model. CGE: Computable general equilibrium model. ME: Market equilibrium model. G: Gross job effects. N: Net job effects.

Figure 7: Gross jobs per £m invested[15] (number of studies in brackets)



Again, given the relatively small number of data points, the results need to be treated with caution. However, at face value, they suggest that in financial terms, coal- and gas-fired generation do not appear to be significantly more job-intensive than RE or EE: possibly the reverse is true, with RE and EE appearing to show a job-intensity of the order magnitude of 5-10 jobs/£m invested greater than for fossil-fuelled power generation. The average from these figures for fossil fuels is about 6 jobs/£m (coal 7, gas 5), whereas for RE is about 16 jobs/£m, for EE 14 jobs/£m, and for RE and EE combined is about 15 jobs/£m.

The range of jobs estimates is relatively large, indicating the sensitivity to different assumptions. One common factor noted by many of the authors is the degree to which local content (e.g. labour and materials) is involved, and in particular the degree to which jobs associated with manufacturing of equipment is included in the estimates, confirming the findings of Cameron and Van der Zwaan (In Submission) presented in Section 2.1.4.

4.2.1 Short-term construction and installation jobs

Analysis in the previous section is concerned with a comparison of total jobs estimates, where short-term and long-term jobs have been combined into a single indicator. However, if the focus of policy is on rapid economic stimulus, then it is the short-term jobs impacts are of separate interest.

Publications which separated out the short-term construction-phase jobs included studies #42, #47, #53, #65, #75 and #F9. In addition, two review papers #19 and #79 provided additional data. The results of these studies are summarised in Figure 8, with average values across the ranges shown in Table 2. The data from study #79 tend to be somewhat higher than for the other studies because they include manufacturing in their definition of short-term jobs, whereas the other studies only include construction and installation jobs.

15 See footnote to Figure 6 for abbreviations key.

Figure 8: Short-term direct jobs during the construction phase of projects[16]

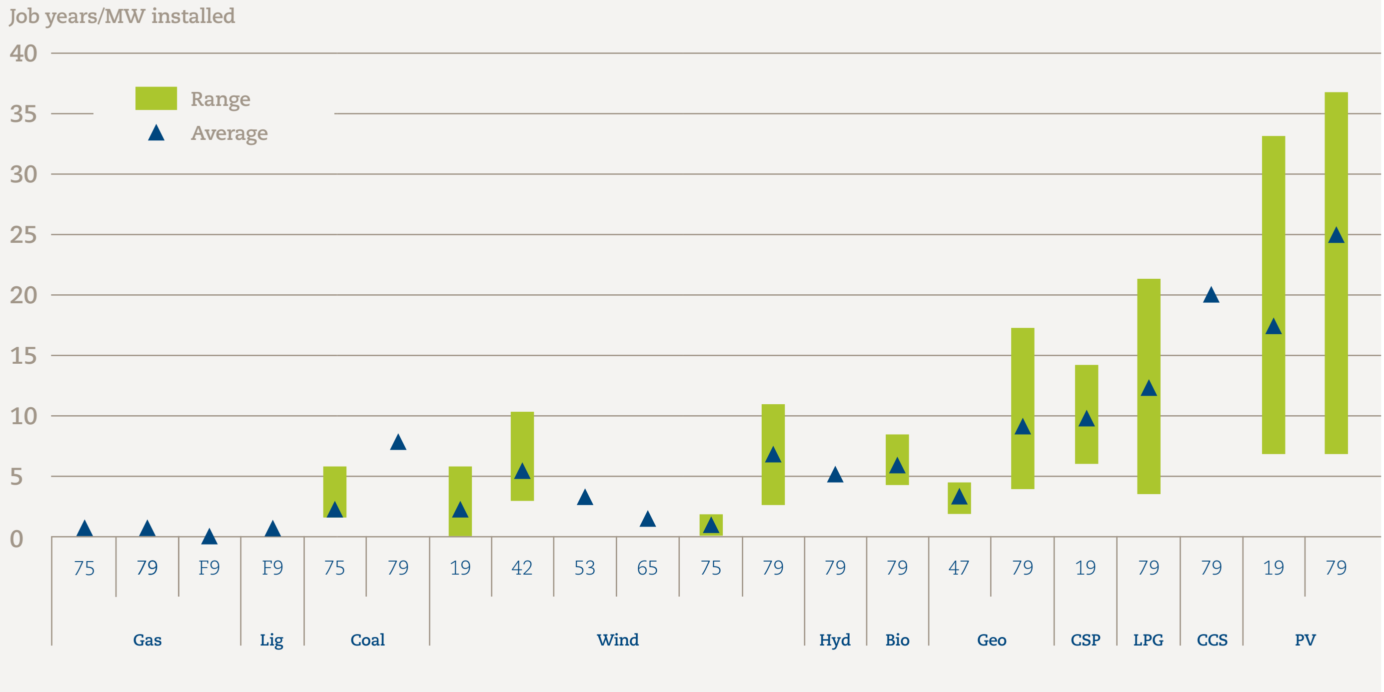


Table 2: Average short-term direct jobs during construction period

Technology	Average short-term employment factor (Job-years/installed MWp)
Gas	1.0
Lignite	1.5
Coal	4.3
Wind	4.5
Hydro	5.7
Biomass	6.4
Geothermal	6.8
Solar CSP	10.2
Landfill Gas	12.5
CCS	20.5
Solar PV	21.6

The data shows that in general, RE sources tend to require more labour during the construction and installation phase than traditional fossil-fuel sources. However, there is quite a wide variation between technologies. Most sources seem to agree that construction of gas-fired plant has the lowest labour intensity, averaging around 1 job year/installed MWp. Coal and wind power have quite similar labour intensities, averaging around 4.5 job years/installed MWp. Estimates for other RE tend to be higher, and in the case of solar PV rising to over 20 job years/installed MWp, largely because of the high labour intensity of the installation phase for small roof-top solar projects.

It should be noted that the choice of units are important here. Comparing RE projects with coal and gas on an installed peak capacity (MWp) basis is not a like-for-like comparison because of the lower average utilisation rates for intermittent RE, especially wind and solar. If the units were changed to compare projects on the basis of average available capacity, or annual electricity output, then the employment factors for wind and solar would be approximately three times higher than shown here. These figures should therefore be taken as a conservative indication of the potential short-term jobs benefits of RE relative to construction of fossil fuel plant.

16 See footnote to Figure 6 for abbreviations.

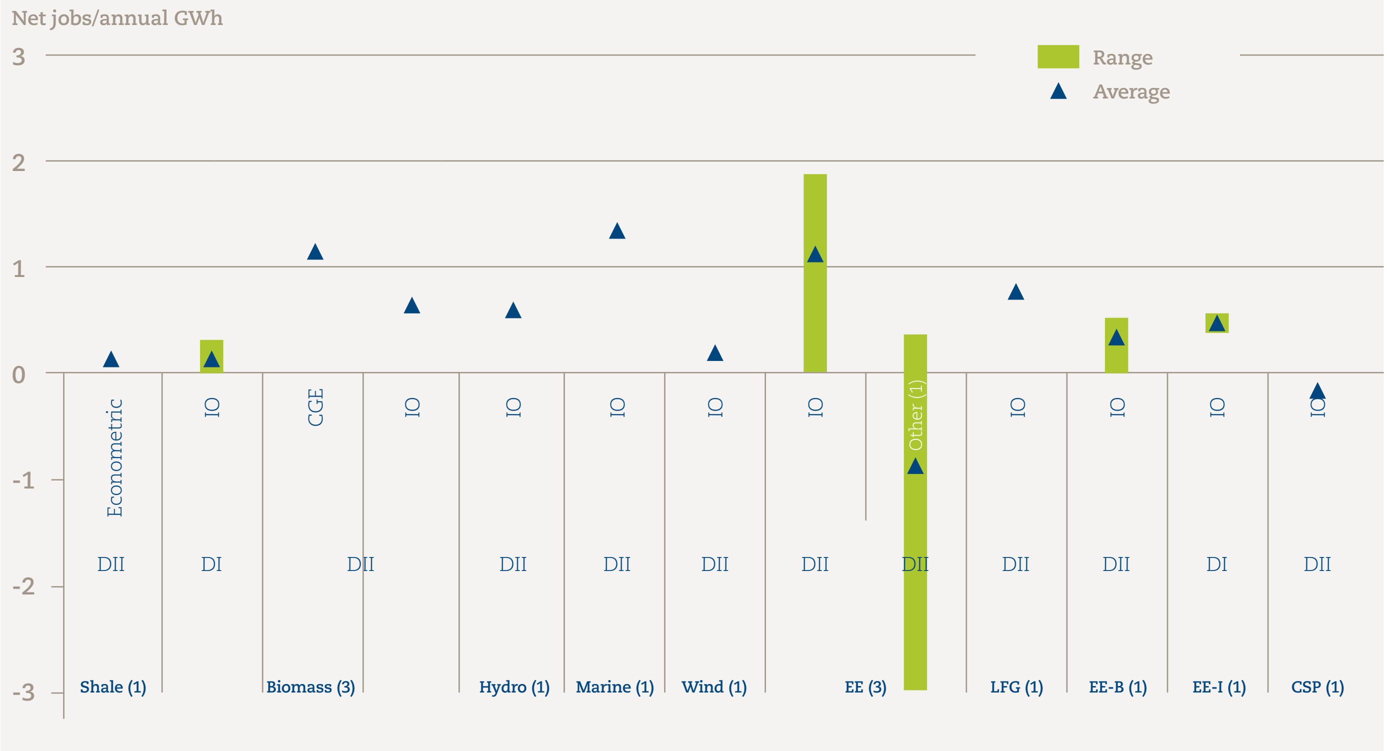
4.3 Net Jobs Summary

Figure 9 summarises figures from the literature which provided net jobs estimates for different RE and EE options. In this chart, fossil fuel generation is not shown as a comparator, because these estimates already contain a comparison with some alternative type of investment (usually a fossil-fuel counterfactual). These data should therefore in themselves represent evidence as to whether or not RE and EE investments lead to net job creation.

On the face of it, the evidence looks remarkably positive. One study shows a negative effect for energy efficiency investment – this result comes from a single study which uses an econometric approach linking energy consumption with employment levels, and is discussed in more detail in Section 4.4.4. Another study shows a slightly negative net effect for CSP. All other studies showed a positive net effect.

The average net job creation across all RE technologies from these figures is about 0.5 jobs/GWh, for EE 0.25 jobs/GWh, and for RE and EE combined is around 0.35/GWh. These net results are of the same order of magnitude as the estimates derived from the gross job results in the previous section.

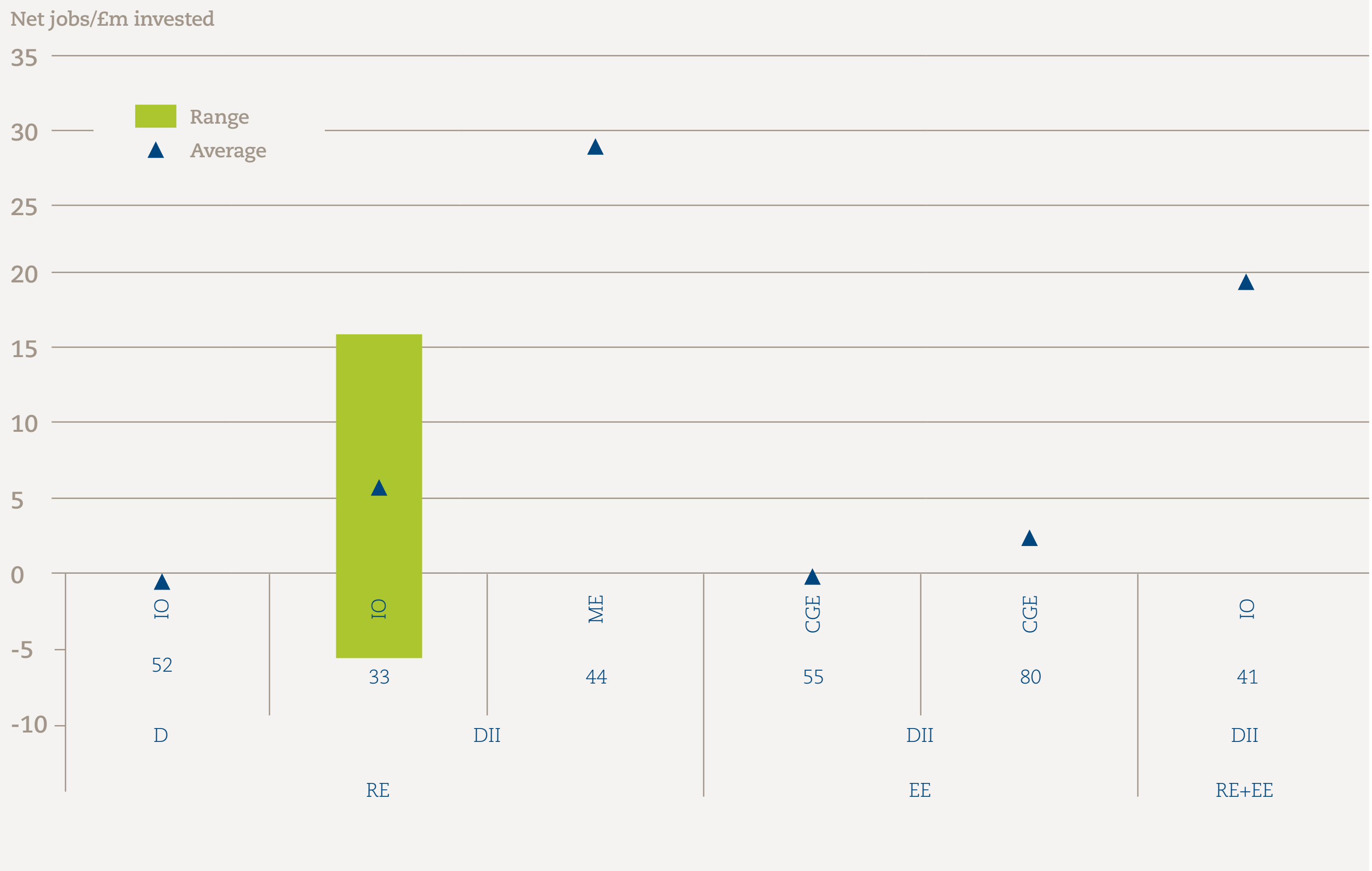
Figure 9: Net jobs per annual GWh generated[17] (number of studies in brackets)



Net jobs estimates based on the financial indicator of jobs/£m invested are summarised in Figure 10. Since there are many fewer studies which provided data suitable for calculating this indicator, each publication is represented individually in the chart. These studies did not split out results for different technologies, but grouped them into overall effects of RE or EE programmes. It can be seen that overall, the general impact across RE and EE is positive from these results, averaging around 10 jobs/£m invested. Again, this effect is roughly consistent with the estimates drawn from gross jobs data in the previous section.

17 See footnote to Figure 6 for abbreviations key.

Figure 10 : Net jobs per £m invested[18]

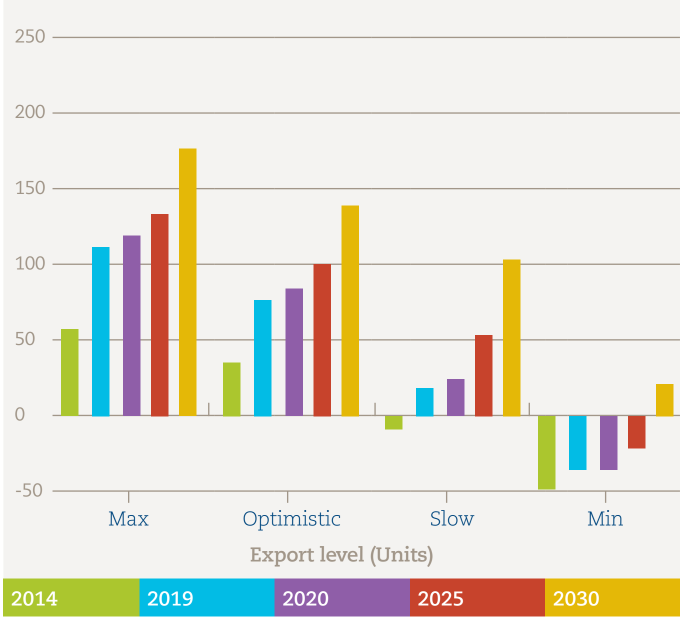


The following points can be noted from each of the studies.

- Study #52 (Marsh and Miers, 2011). This non peer-reviewed report finds a small net negative impact from UK RE policies. They arrive at this result by comparing the level of gross job creation from RE with an alternative of using the money instead to cut VAT levels. Using an input-output model, they arrive at a higher job creation figure for the tax cut, implying a net negative job impact for RE relative to this opportunity cost.
- Study #33 (Hillebrand *et al*., 2006). This peer-reviewed paper deploys input-output modelling together with several other model components which take into account dynamic effects as well as effects on household disposable incomes. RE investment in Germany is compared with a reference scenario of CCGT plant, and impacts on the wider electricity system, such as changes to back-up capacity and grid reinforcements, are included in the assessment. A particular innovation of the paper is to look at dynamic employment effects: the range shown in Figure 6 represents the range of job impacts over a six-year time period. The highest positive impacts occur during the early stages of project construction. The number of net jobs created then falls, becoming negative after six years once the impact of higher prices from RE start to be felt in the wider economy.
- Study #44 (Lehr, 2008). This peer-reviewed paper uses a macro-econometric model to compare a reference scenario based on a continuation of Germany's (then) current policies, with a more ambitious RE programme over the period to 2030. The paper identifies a significant positive employment effect from the more ambitious RE programme, but the author shows that this result is dependent on a strong international market for RE providing Germany with a strong export market. This sensitivity is supported by later work by the same author which shows that without strong exports, the labour impacts of RE are smaller, and could go negative under a minimal exports scenario (Lehr *et al*., 2012).

18 Numbers in the x-axis refer to publication index numbers from the Appendix table, See footnote to Figure 6 for abbreviations key.

Figure 11: Employment effects (y axis units are 1,000 persons), difference between RE and reference scenario (from Fig 4, Lehr et. al 2012)



- Study #55 (Moscovitch, 1994). This peer-reviewed paper uses a CGE model to look at employment effects of a demand-side management (DSM) programme in the US. The dynamic economic effects are the reverse of those shown in Study #44; since DSM requires initial capital outlay, there is a short-term decrease in disposable income for households, whilst in the longer term the cumulative effect of energy savings relative to the reference case builds towards increasing disposable income over time. Total employment is shown to be essentially unchanged between the DSM and reference scenarios, although there are important re-distributional effects between sectors.
- Study #80 (Weisbrod *et al.*, 1995). This non-peer-reviewed report looks at state-level employment effects of DSM in Iowa. The study involved a detailed survey of suppliers of EE equipment in Iowa, US, with IO modelling and simulation of job leakage and price effects. The study found a small net positive effect on employment, although again there was a time dimension to this. The annual job estimates, calculated over a ten year period, reflect a first-year gain due to the purchasing and installation of program measures, followed by a pattern of losses attributable to financing in the next few years which were then made up by gains in the latter years as the value of energy savings accumulated.

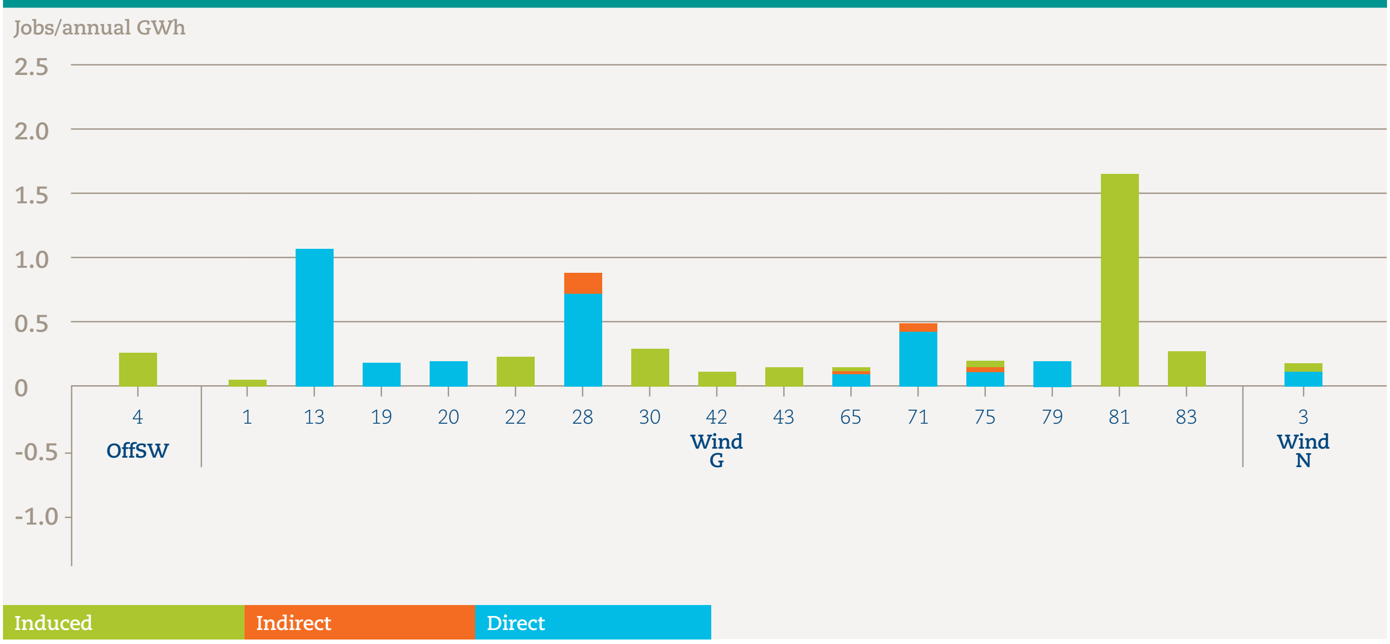
4.4 Breakdown by Technology

Section 4.2 presented results of gross jobs impacts aggregated across multiple studies. This section returns to the gross jobs estimates (measured per GWh electricity generated), but presents results of individual studies, allowing a more accurate assessment of the variation of estimates between publications. In several cases, individual publications present a range of estimates which provide useful information on the sensitivity of jobs estimates to different input assumptions. These cases are drawn out in the discussion below for each technology.

4.4.1 Wind

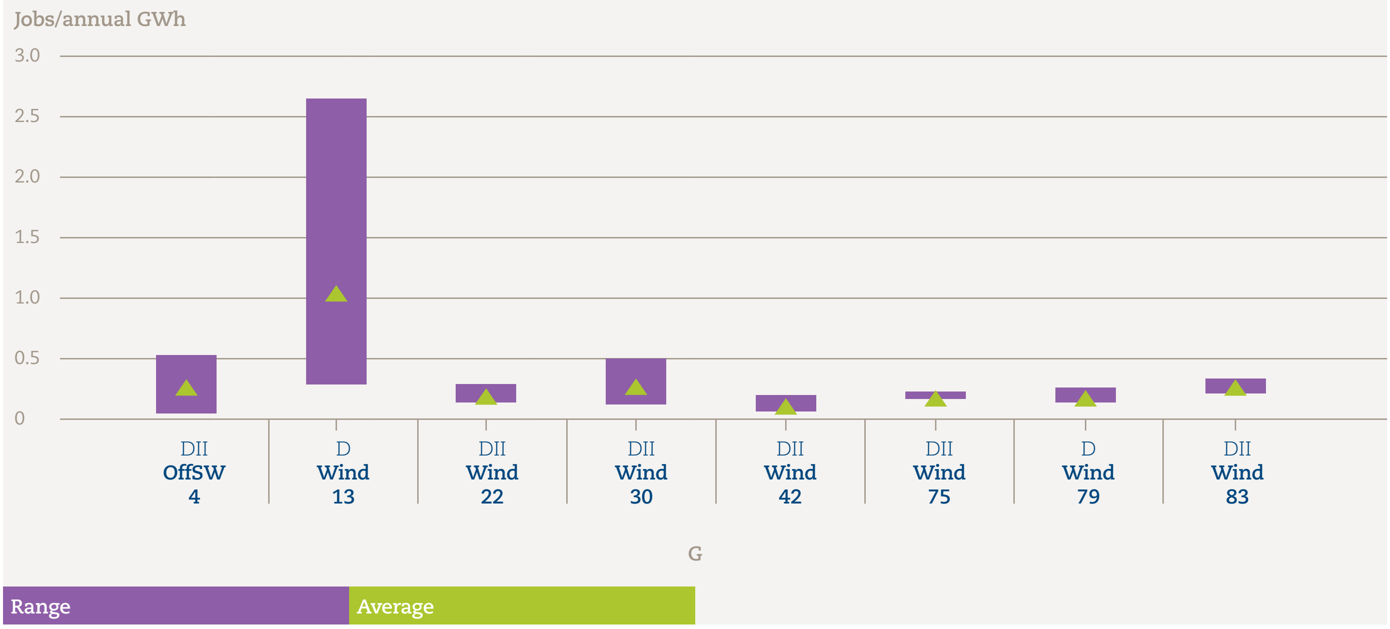
Figure 12 shows the average job estimates of individual publications for the number of jobs per unit of electricity generated. Figure 13 shows the results of publications that provide a sensitivity range. Most of the results lie in the range 0.05-0.5 jobs/annual GWh.

Figure 12: Average results from individual publications; Wind[19]



19 See footnote to Figure 6 for abbreviations key.

Figure 13: Sensitivity ranges from individual publications; Wind[20]



Three studies stand out as having higher employment factors:

- Study #81 (Whiteley *et al.*, 2004). This is a non-peer-reviewed report which aggregates a large number of modelling studies for each country of the EU. Whilst it appears to be based on detailed modelling, the assumptions were not clearly set out, and it was not possible to ascertain why these results were larger than the mainstream estimates.
- Study #28 (Faulin *et al.*, 2006). This peer-reviewed paper presents results of a local employment impact study for the Navarre region of Spain which saw disproportionately high economic benefits from Spain's expansion of wind energy. The high benefits resulted from the good wind potential of Navarre, combined with the relatively poor economic status of the region compared to Spain as a whole. Whilst the assumptions and results appear robust for this setting, it is not clear that they would necessarily translate to other regions or national level impacts.
- Study #13 (Blanco and Rodrigues, 2009). The authors of this peer-reviewed paper carried out an extensive survey of firms operating in the wind energy sector. The range shown in Figure 9 is the range of employment levels in different countries, divided by the total supply of electricity from wind in that country. The figures range from over 2 jobs/annual GWh for smaller countries with manufacturing export potential, such as Denmark, to around 0.3 jobs/annual GWh for Czech Republic and Austria. Large 'mainstream' countries deploying wind were somewhere in the middle of the range (e.g. Germany 1.7, and Spain 1.4 jobs/annual GWh), reflecting their larger domestic consumption, but also some export potential.

These results reinforce the message from Figure 5 that the presence of manufacturing capacity in a country is particularly important for wind, and even more so if there is export potential for the technology. These results are also noted in other studies. For example, comparison of different employment effects between different states in the US have been made by Lantz and Tegen (2008) who note that:

> *"the single greatest local supply parameter affecting economic development benefits is the supply of wind turbines and their components. Wind turbines frequently constitute 65% to 85% of the total construction cost for a new wind farm.21 As a result, increasing the in-state supply of wind turbines from 0 to10% provides a 68% increase in construction-period economic development impacts. Moving from 0 to 50% in-state manufacturing generates a 341% increase in construction-period impacts. As such, the single largest potential driver of economic development benefits is local manufacturing."*

The same authors also note that the proportion of local content (local supply of materials and labour) during the operation and maintenance phase of a project also has a strong influence on local employment benefits, noting that "If routine maintenance is performed by crews that travel from one wind farm to the next performing regular and major maintenance, states may see a drop in local labor utilized during the operations".

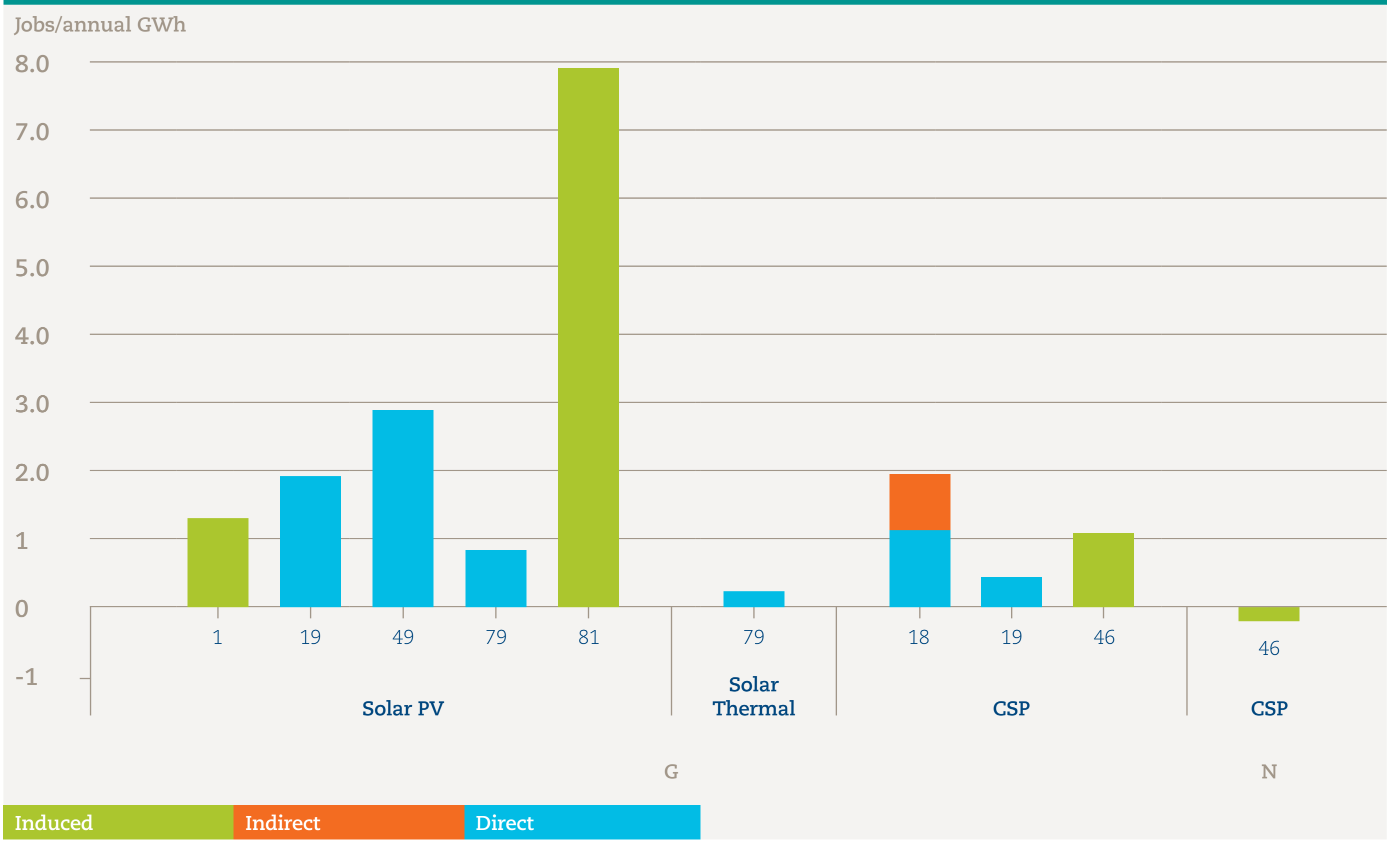
20 See footnote to Figure 6 for abbreviations key.

Some studies focus on very localised employment effects, and it is important in these cases to look at the details of the financial arrangements for the projects. Study #4 (Allan *et al.*, 2011), and #30 (Goldberg *et al.*, 2004) looked at a range of different ownership structures for wind plant, showing that local ownership leads to considerably higher (induced) local job impacts because of the greater retention of economic benefits in the local area. This explains the range of results shown for these studies in Figure 13.

4.4.2 Solar

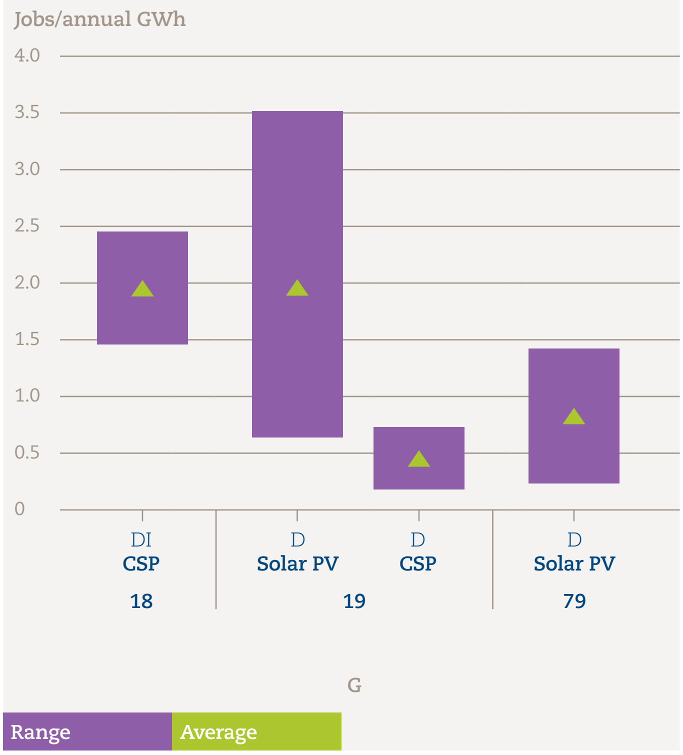
The results of individual studies for solar technologies is shown in Figure 14 (averages) and Figure 15 (sensitivity ranges). Most of the papers give employment factors for solar in the range 0.4 1.1 jobs/annual GWh. As was the case for wind, study #81 appears to be something of an outlier, although it includes indirect and induced job impacts, which many of the other studies exclude. Study #46 (Lenzen and Dey, 2002) is the only study to provide estimates for both gross and net job impacts. They show a positive gross job creation for concentrated solar power (CSP), but show that this figure is smaller than the average employment impacts associated with Australia's thermal power generation system.

Figure 14: Average results from individual publications; Solar[21]



21 See footnote to Figure 6 for abbreviations key.

Figure 15: Sensitivity ranges from individual publications; Solar[22]



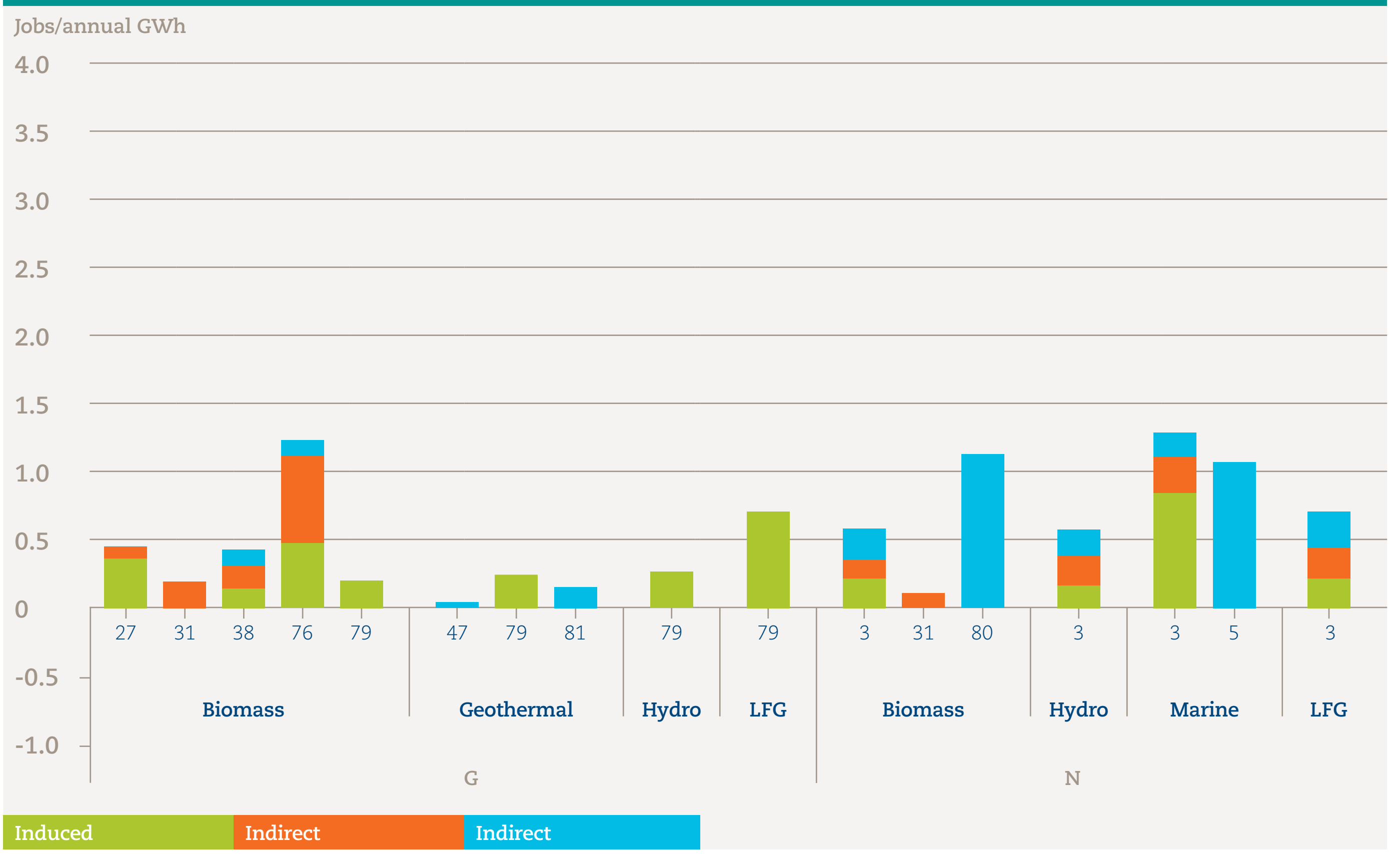
The ranges shown in Figure 15 reflect the following factors:

- Study #18 (Caldés *et al.*, 2009) presents employment impacts for two different CSP technologies applied in Spain, with the solar tower having a higher labour intensity per unit of electricity generated than the parabolic trough.
- Studies #19 (Cameron and Van der Zwaan, In Submission) and #79 (Wei *et al.*, 2010) are both literature reviews, and represent the range of values found in the sources of literature covered. As far as possible, these sources have been de-duplicated from the sources found as part of this systematic review.

4.4.3 Other Renewables

The results of individual studies for other RE technologies is shown in Figure 16 (averages) and Figure 17 (sensitivity ranges). The results show a wider range of variation than for solar and wind, partly because of the diverse set of technologies represented here. One pattern that was noticeable in the literature was the relatively high indirect employment multiplier for biomass plant because of the impacts on the agricultural sector.

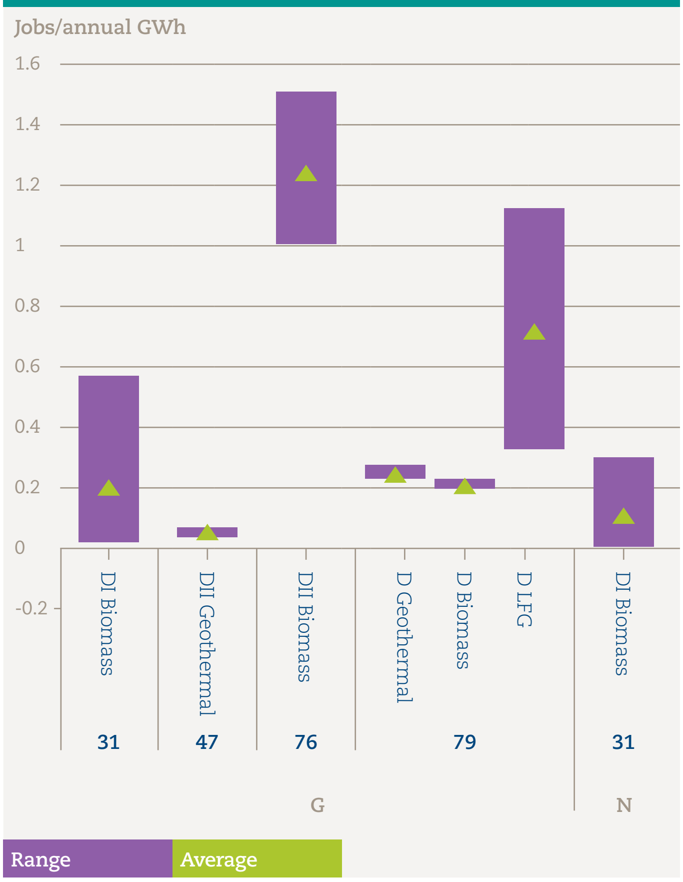
Figure 16: Average results from individual publications; Other RE[23]



22 See footnote to Figure 6 for abbreviations key.

23 See footnote to Figure 6 for abbreviations key.

Figure 17: Sensitivity ranges from individual publications; Other RE[24]



The ranges shown for study #79 (Wei *et al*., 2010) represent the range of results found in their literature survey, comprising two studies for biomass, three studies for geothermal, and two studies for land-fill gas. Details of those studies are not provided, so it is no clear what drives the ranges shown. Study #47 (Lesser, 1994) shows a range of impacts for geothermal depending on application to two different locations in Washington State, US, with local infrastructure and labour market conditions affecting the employment impacts.

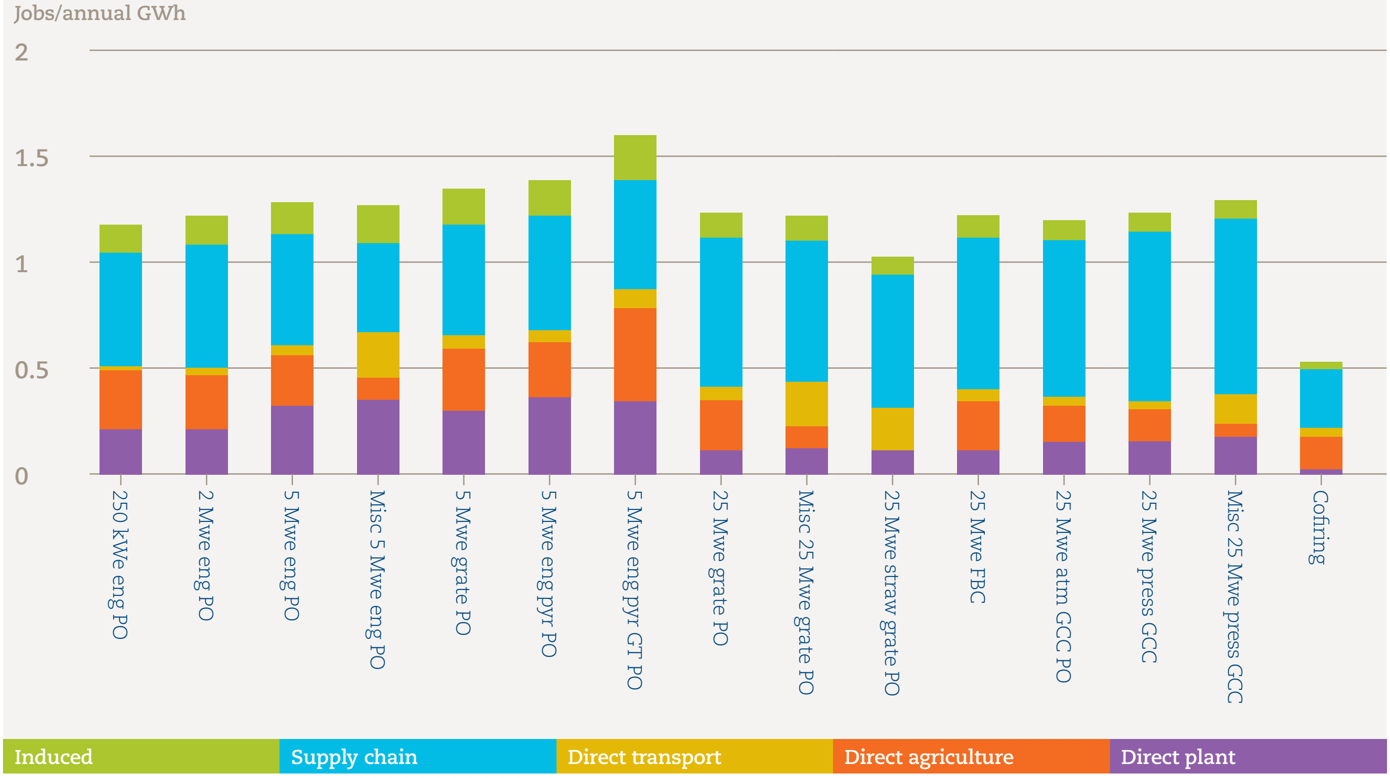
Comparing studies #31 and #79, they appear to have very different estimates of the gross employment impacts of biomass. However, on closer inspection, the ranges are not so far apart when it is taken into account the range of technologies and fuel pathways included in each study:

- Study #31 (Groscurth *et al*., 2000) provides results of five different case studies with a variety of different fuels. The results show that in general, use of forest residues and other wood-based wastes result in lower employment intensity than dedicated crops, such as short-rotation coppice, which are at the upper end of the range shown here.
- Study #76 (Thornley *et al*., 2008) provides employment estimates for a range of different biomass combustion technologies of different sizes, but the fuel assumptions are dominated by dedicated biomass crops, mostly short-rotation coppice or Miscanthus.

The higher employment impacts of dedicated biomass options reflects the significant impacts on the agricultural sector, which itself then feeds through to higher indirect and induced effects on the supply chain for the affected sectors. A breakdown of job impacts by sector is given by Study #76 (Thornley *et al*., 2008), an extract of which is shown in Figure 18. The figure shows that agricultural sector impacts are of the same order of magnitude as the direct plant employment effects, though they are considerably smaller in the case of Miscanthus- and straw-based plant.

24 See footnote to Figure 6 for abbreviations key.

Figure 18: Breakdown of job impacts by sector for biomass

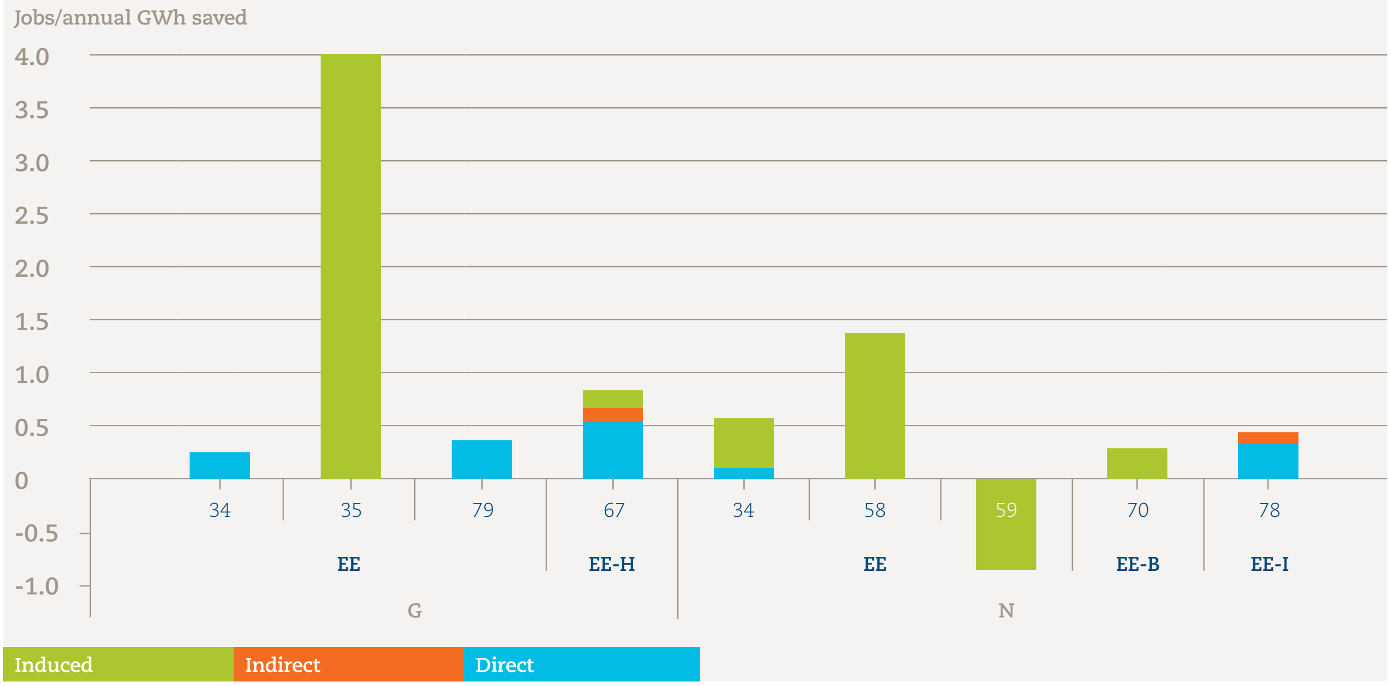


Source: Thornley *et al.* (2008)

4.4.4 Energy Efficiency

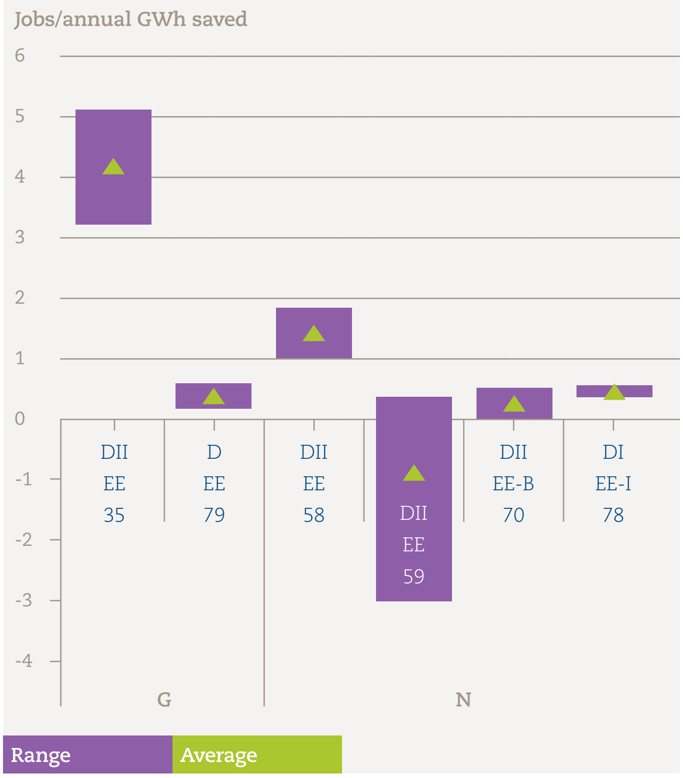
The range of estimates for the job impacts of EE appears to be wider than for RE, as indicated in Figure 19. Most of the studies give estimates in the range of around 0.3-1 jobs/annual GWh saved. Study #35, #58 and #59 appear to be well outside this range. These publications are discussed in more detail below.

Figure 19: Average results from individual publications; Energy Efficiency[25]



25 See footnote to Figure 6 for abbreviations key.

Figure 20: Sensitivity ranges from individual publications; Energy Efficiency[26]



Information about the sensitivity of these job estimates can be drawn from studies which present a range of results (as shown in Figure 20) as follows:

- Study #35 (Kaiser *et al*., 2005). This peer-reviewed study looks at the impacts of the Louisiana Energy Fund which was designed to provide publicly funded institutions support to implement energy conservation projects under performance-based contracts with energy service companies (ESCOs). The applications were mainly in schools and other public buildings. It is not clear from the data provided in the publication as to why the estimates might be so much higher than other estimates of EE employment impacts. The range is driven by different estimates of how much energy would be saved by the fund (the lower savings figure resulting in a higher employment factor).
- Study #79 (Wei *et al*., 2010). This peer-reviewed literature review covers estimates from two different studies, but without details as to what drives the range presented.
- Study #58 (Paul *et al*., 2010). This peer-reviewed paper models the impact of spending carbon revenues from the regional greenhouse gas initiative (RGGI) on energy efficiency measures in Maryland, US, including retrofit and new-build EE measures in domestic and commercial buildings. The range depends on the extent to which revenues are allocated to EEigher employment intensity is associated with a higher level of EE spending, presumably reflecting diminishing returns in terms of the amount of energy saved as the programme is expanded towards harder-to-reach projects.
- Study #59 (Marvão Pereira and Marvão Pereira, 2010). This peer-reviewed paper uses an econometric model to show a positive historical correlation between energy use and employment levels (for gas and electricity), though this relationship is reversed in the case of coal. The authors use this relationship to infer that energy savings programmes will lead to job losses, except in the case of reductions in coal use. However, the publication does not appear to provide evidence to support the assertion of going beyond correlation to prove that directional causality holds, so this result appears rather questionable.
- Study #70 (Scott *et al*., 2008). This peer-reviewed paper looks at the net impact across the whole US of the Department of Energy Building Technologies Budget. This mostly comprises accelerating uptake of EE practices in new residential and commercial buildings (including building codes), as well as support for emerging technologies and equipment standards. The range shows how the induced job impacts evolve over time. In the early stages of the programme, energy savings do not have a material economic impact, but as savings accumulate, they drive a wedge between the reference scenario and the EE scenario, opening up greater benefits over time (in this case over a 25 year modelling horizon).
- Study #78 (Varma and Medhurst, 2007). This report compares two different applications of industrial energy efficiency, the first associated with a broad-based programme across all industry sectors, the second focused on the energy-intensive industries. The study finds that the latter would lead to a high level of savings per job, represented by the lower end of the range of job intensities shown in Figure 17, though this range is relatively tight.

4.4.5 Fossil Fuels

The studies which provide estimates of employment factors for fossil fuels are shown in Figure 21 (average values). Most of the studies provide estimates in a narrow range of between 0.1-0.2 jobs/annual GWh. As far as was possible to determine, the results presented here are independent estimates, and range across a number of different countries including Greece (#F9), Scotland (study #3), Netherlands (study #27), various EU countries (study #31) and the US (studies #75, #79, #F5, #F12).

26 See footnote to Figure 6 for abbreviations key.

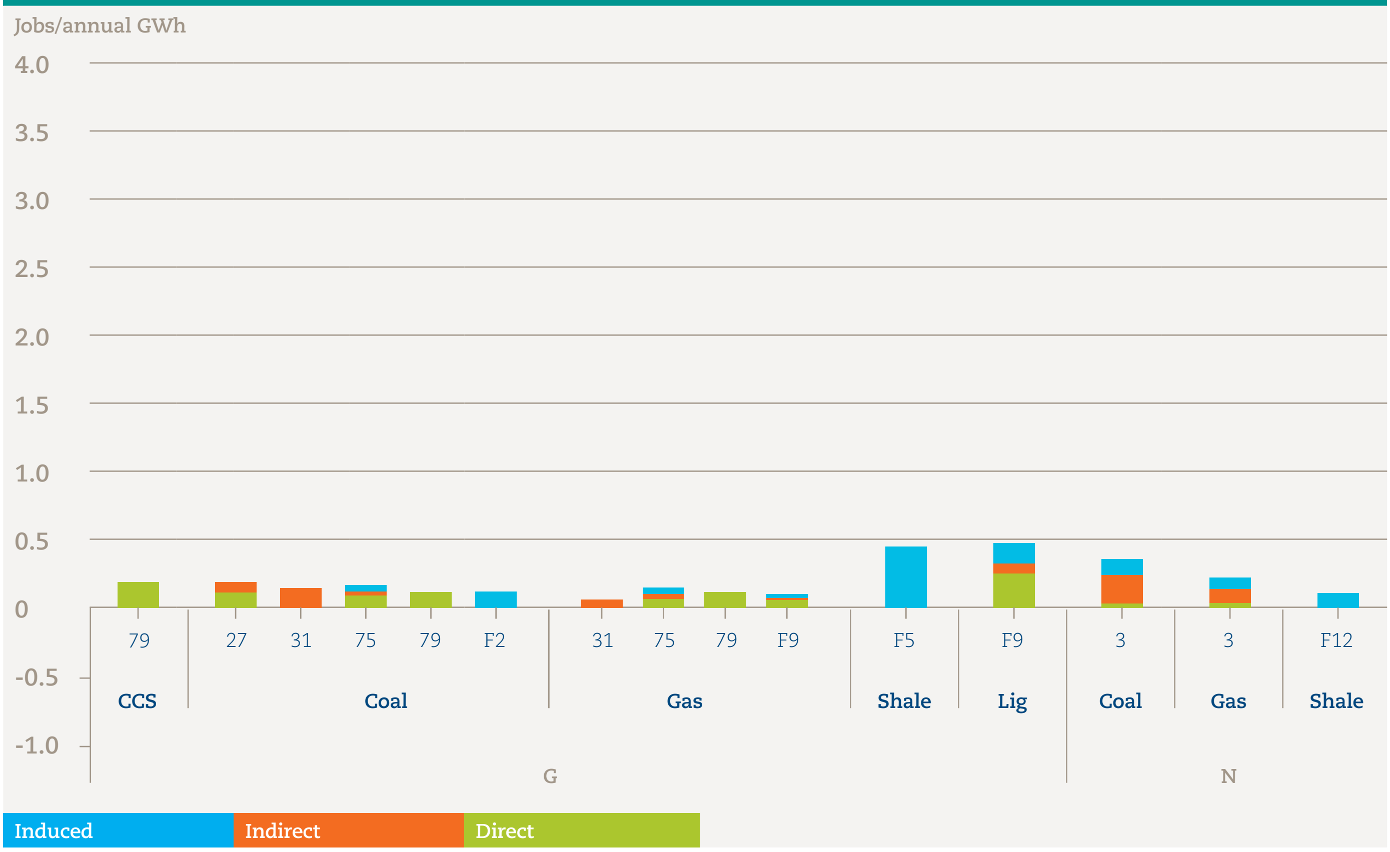
Study #F9 (Tourkolias *et al.*, 2009) compares two different case studies in Greece, a lignite plant and a combined cycle gas turbine (CCGT) plant, and finds significantly higher employment factors for the lignite plant (0.45 jobs/annual GWh) compared to the gas plant (0.1 jobs/annual GWh). About two-thirds of the difference between the two can be accounted for by the extraction and transportation elements of the lignite fuel cycle (in this study counted as direct jobs) which happens within Greece, whereas gas is imported, so the upstream fuel cycle does not create jobs within the region being assessed.

A similar result is found for coal by Study #3 (Allan *et al.*, 2007b) which shows strong impacts on employment in the coal mining sector (in this study counted as indirect effects) associated with coal, bringing the total direct, indirect and induced employment up to 0.34 jobs/annual GWh. Results #3 and #F9 show that the employment factor for solid fuels is likely to be strongly affected by whether or not there is local mining capacity to supply the fuels for power generation.

Shale gas has been included here by converting the energy content of the gas itself to an electricity equivalent by assuming that it would be used in a CCGT with a 60% efficiency rating. This puts the denominator of the employment factor on an equal footing with the power generation projects. However, the numerator only counts jobs in the upstream part of the shale gas fuel cycle. That means that the employment factors shown in Figure 21 for shale gas are additional to the factors shown for gas generation in the same figure.

Estimates for employment impacts of shale gas differ in the literature. Study #F5 (IHS Global Insight, 2011) is a non-peer-reviewed study carried out on behalf of America's Natural Gas Alliance using IO modelling. The study puts the figure relatively high at 0.45 jobs/annual GWh. This figure is challenged by study #F12 (Weber, 2014) which uses econometric techniques to assess ex-poste employment effects, comparing different counties in the US with different levels of shale gas exploitation. Weber suggests that the employment multiplier of 9 between induced and direct jobs found by the IHS study is too high, with multipliers around 2.4 appearing to better fit the empirical data.

Figure 21: Average results from individual publications; Fossil Fuels[27]



27 See footnote to Figure 6 for abbreviations key.

Figure 22: Sensitivity ranges from individual publications; Fossil Fuels[28]

The two studies which present a range of employment factors as presented in Figure 22 explore the following sensitivities:

- Study #31 (Groscurth *et al.*, 2000). This peer-reviewed paper presents figures for a range of fossil-based counterfactuals in their analysis of job impacts of biomass. These counterfactuals include combustion of imported coal in thermal power generation units in the UK and in Sweden.
- Study #75 (Tegen *et al.*, 2006). This report uses the National Renewable Energy Laboratory's JEDI[29] model to compare employment factors for coal, natural gas and wind. The factors are based on standard default data in the JEDI database which is based on national US employment statistics, broken down to provide state-level detail. This paper compares the different employment impacts across three states, Colorado, Michigan and Virginia. The range presented shows the sensitivity to location, and the degree to which local coal or gas resources are used to benefit from upstream energy-sector impacts.

4.5 General Equilibrium Studies

As described in the previous sections, most of the quantitative papers assessed during this review arrived at their results through a combination of case studies and surveys, often combined with input-output modelling. The number of CGE studies identified by the literature review was relatively small, and comprised the following papers (for technologies within the scope of the review):

Study #	Reference	Used in Quant Review?	Technology/ policy	Main features of the paper
5	Allan *et al.* (2008)	Y	Marine	Provides estimates of the number of net jobs in Scotland associated with development of marine-based renewables, taking account of displaced jobs and price effects.
14	Böhringer *et al.* (2013)	N	All RE	Assesses macro-economic impacts of Germany's programme of support for RE across all technologies. Not possible to extract employment factors, but useful data on importance of the source of finance (see below).
16	Buddelmeyer *et al.* (2008)	N	Climate policy	Mostly concerned with overall economic impacts, no significant employment analysis.
21	Chateau and Saint-Martin, (2013)	N	Carbon pricing	Mostly concerned with impacts of carbon pricing and tax, with results of revenue recycling, and with double dividend effects in the presence of labour market imperfections.
55	Moscovitch, (1994)	Y	EE	Simple CGE model that assumes economy remains always in equilibrium, hence there is no impact on employment of EE measures.
80	Weisbrod *et al.* (1995)	Y	EE, biomass	Assessment of net employment from DSM programmes and small-scale biomass plant

28 See footnote to Figure 6 for abbreviations key.
29 Jobs and Economic Development Impact Model

For two of these studies (#16 and #21), data relevant to the research question could not be extracted. For three out of six of these CGE papers (#5, #55 and #80), it was possible to extract quantitative data for net employment factors and these were incorporated into the analysis of the previous sections. These CGE studies did not show any particular trend regarding the estimated employment factors compared to the other studies. For example, two estimates by the same author for marine power in Scotland, using different modelling techniques, arrived at similar employment factors: study #3 using IO models, and study #5 using CGE gave figures of 1.3 and 1.1 jobs/annual GWh respectively (Figure 16). Study #80 for biomass gave relatively high employment factors when compared to other studies (Figure 16). On the other hand, study #55 gave an employment factor of zero for EE because of the explicit assumption of equilibrium being maintained. Study #80 also gave an employment factor for EE that was low relative to other studies.

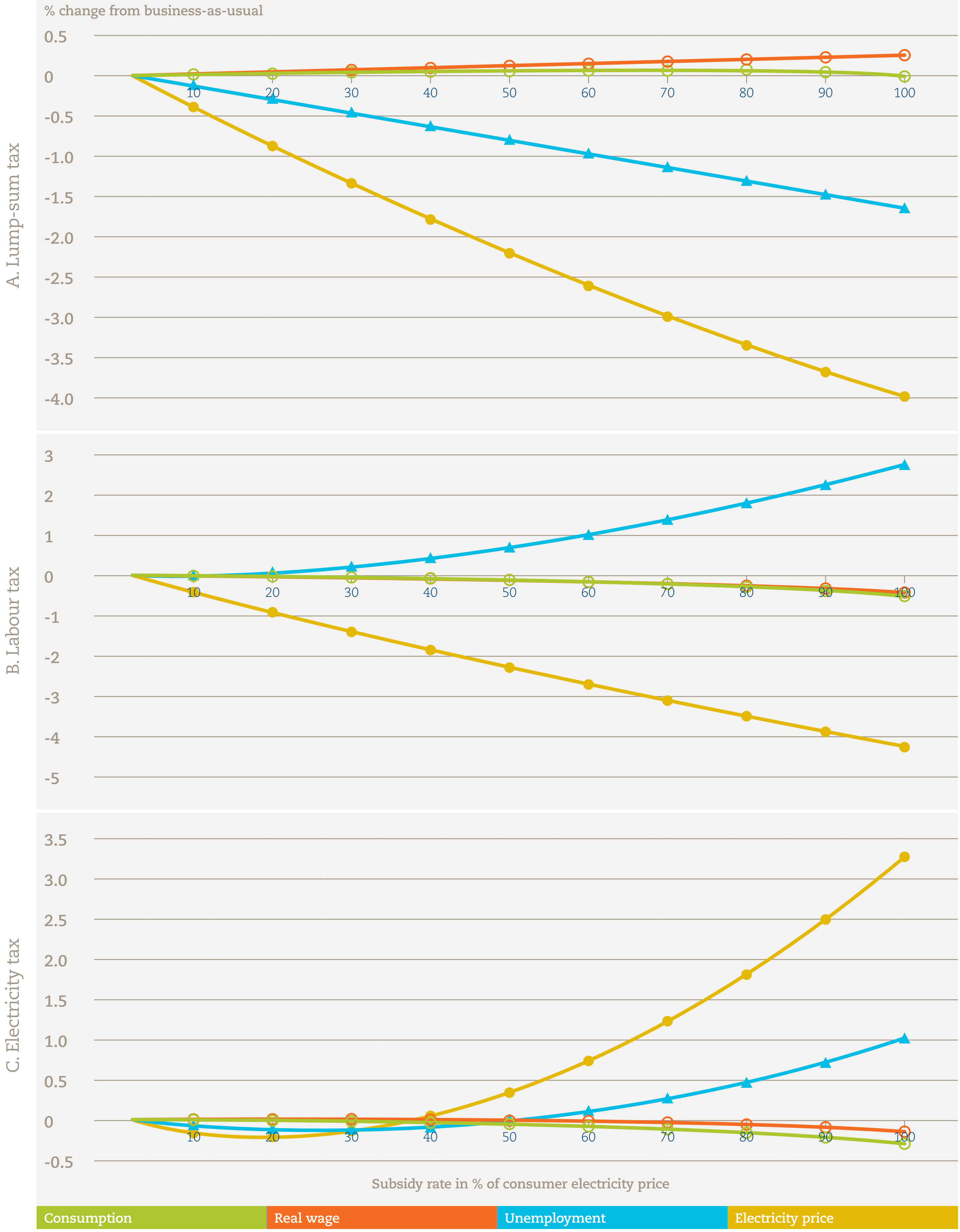
It does not therefore seem *a priori* that one type of modelling will tend to give a higher or lower estimate than another. The results are more driven by the particular circumstances being assessed, in terms of technology, labour market conditions, price assumptions etc.

Study #14 Böhringer *et al.* (2013) provides relevant data, but could not be incorporated into the quantitative comparison of the previous sections. This study looks at the macro-economic impacts of meeting Germany's RE targets, incorporating labour-market rigidities in order to incorporate unemployment into the model. In this situation, wage rigidity prevents the economy from efficient resource use. The subsidy then has two effects. First, it promotes employment by stimulating domestic energy production and increasing the demand for labour in the domestic energy sector. Second, it increases energy use and hence the marginal productivity of labour in final goods production (this effect is linked to the impact of RE on suppressing wholesale electricity prices). This in turn increases the demand for labour in this sector, until the marginal productivity of labour corresponds to the rigid wage rate again. Both effects induce an increase in labour demand, so unemployment falls. However, the fall in unemployment in the final goods sector will be dampened by the resultant increase in wages in that sector. This means that welfare only increases up to a certain level of subsidies – beyond this level, the final goods sector is harmed by the increase in wage levels, and overall welfare starts to decline.

The paper also assesses sensitivity of the employment impact on how the RE subsidies are financed. Results are reproduced in Figure 23 for three of the different funding scenarios. In Scenario A, the subsidies are financed by a one-off lump-sum tax on consumers. Because the tax is a lump-sum, it does not affect marginal consumption behaviour. Increasing levels of subsidy lead to greater reductions in the unemployment rate, although there is a peak in consumption (i.e. total welfare) at a subsidy rate of around 50%. Under Scenario B, financing the RE subsidy through labour taxes leads to higher unemployment and welfare losses at all levels of subsidy. In this scenario, increases in the distortionary effects of labour taxes in the economy swamp the effect of the subsidy on domestic energy production and lower electricity prices on employment demand.

The final case, Scenario C, is the closest match to the actual policy design in Germany, where RE subsidies are financed by a levy on electricity sales prices. In this situation, lower levels of subsidy (up to around 30%) have a positive effect in terms of reducing unemployment and improving welfare, but this situation reverses with increasingly negative impacts at higher levels of subsidy.

Figure 23: Importance of the source of financing on employment and welfare.



Source: Bohringer *et al* (2013)

The results of Böhringer *et al.* (2013) provide an important supplement to the results derived from IO models presented in the previous sections. Scenario A, where consumer behaviour is assumed to be unaffected by the RE subsidy, is quite similar to the set-up of many IO studies, where RE investments are assumed to be financed as an external economic stimulus. In this situation, the CGE and IO results are qualitatively similar. However, when more realistic assumptions are made about the source of financing, this work indicates that the additional cost of RE can have important negative effects, especially at high levels of subsidy support. Nevertheless, Scenario C reinforces the results of the IO studies to some extent, indicating that at least for low to moderate levels of subsidy, positive employment and welfare gains can result from support for RE financed through a retail tax on electricity. However, employment impacts may be significantly dampened by the impact on electricity prices compared to IO studies which exclude this effect.

Finally, it should be noted that none of the CGE studies reported here included any external costs, and therefore did not factor in the environmental benefits of RE relative to traditional fossil fuels. Nor did they factor in any of the potential dynamic efficiency benefits of supporting early stage market development for RE as a way of smoothing the necessary transition towards a low-carbon economy. In this sense, whilst they took account of some aspects of macro-economic dynamics, they were still taking a short-term perspective relative to the multi-decadal problem of decarbonisation.

Summary & Conclusions

5

This report has collated evidence from a wide range of literature regarding the net employment effects of renewable electricity (RE) and energy efficiency (EE). The quantitative analysis of the literature has followed along three separate lines of evidence:

Firstly, an assessment based on gross job estimates, comparing the labour intensity of RE and EE vs. traditional fossil fuel-based generation. This comparison has the advantage of being methodologically simple, and had the largest data-set on which to base the analysis, since most publications reviewed were concerned with gross jobs. The disadvantage of this approach is that it excludes the effect of these investments on electricity prices, and also requires comparing results between different publications which may have used different (possibly incompatible) assumptions and methodologies. As pointed out by Blanco and Rodrigues (2009), it can be misleading to assume that employment factors calculated for a project in one particular location will be transferable to another location with different characteristics. Many factors influence the results, including assumptions about whether or not local labour force is utilised in the project for construction and operation phases, the extent to which economic benefits remain in the local community, the existence of manufacturing capacity for the RE EE equipment within the region, and whether or not employment in the upstream fuel supply (e.g. coal mining) comes within the scope of the analysis. Variations in these factors lead to significantly different calculated employment factors. Nevertheless, when the causes of these variations are taken into account, the literature provides a reasonably coherent overall picture, and seems to support the basic hypothesis that RE and EE are at least as labour intensive when measured in investment cost terms, and more labour intensive when measured in terms of electricity output.

Secondly, a significant number of publications provided their own estimates of net jobs. Sometimes these used a similar approach as above, comparing gross job estimates for RE EE against fossil-fuel plant, whilst in other cases a more integrated approach was taken. Three studies calculated negative net impacts, either because of comparison with more labour intensive alternative investments (studies #46 for CSP, #52 for generic RE), or because of the particular methodological approach taken (#59 for EE). On the other hand a total of thirteen studies calculated positive net impacts for RE and EE, across a range of different technologies. Taken as a whole, these results would therefore also seem to support the conclusion that RE and EE are more labour intensive, and can lead to net positive gains in employment.

Thirdly, evidence regarding the impact of RE and EE investments on electricity prices was assessed. One of the biggest weaknesses of the first two approaches discussed above is that they generally do not take into account the potential knock-on effects on the wider economy of changes in electricity prices resulting from increased levels of RE and EE. Evidence from the literature regarding the importance of the electricity price effects was quite mixed. One study (#33) which explicitly extended the IO methodology to look at monetary effects of RE policy noted a transition from positive employment impacts in the early construction stages of RE projects, to negative impacts later once the price effects had fed through to consumers. On the other hand, the three CGE[30] studies for which employment factors could be derived, all showed positive employment impacts[31]. One of the more nuanced CGE studies (#14) noted that the employment impacts of RE (including price effects) could be positive or negative depending on the source of money used to finance the investments. Using labour taxes tended to exacerbate economic distortions, leading to increases in unemployment, whereas financing through electricity taxes could lead to employment and welfare gains, but only up to a certain level of subsidy, beyond which employment and welfare would begin to decline again.

Many other publications were reviewed both supportive of, and critical of the claims made about green jobs, but which could not be incorporated into the formal comparative analysis. From this literature, it is clear that there are many factors which strongly influence the results of any particular study:

- One of the strongest influences on authors' views regarding the level of green jobs that could be created, was the choice of counterfactual – i.e. the assumption about what would have been done with the money had it not been spent on RE and EE investments. The most 'pro' green jobs literature simply ignores counterfactuals, and assumes that the number of gross jobs created by a particular investment is the total number of jobs added to the economy. Except in particular circumstances (e.g. where a study is focussing very explicitly on localised effects), this assumption is clearly inappropriate. However, there is no generally accepted view regarding what constitutes a 'fair' comparison. Several publications critical of the green jobs agenda (e.g. Huntington (2009), Lesser (2010) and Marsh and Miers (2011)) use a more challenging set of counterfactuals, comparing RE and EE with employment factors drawn either from the wider economy in general, or specifically choosing sectors with particularly high employment factors (such as the construction industry) as the comparator. The rationale for their choice is to point out that the electricity sector employs relatively few people, and that if job creation is the goal of economic stimulus policy, then money should be targeted to sectors with the highest employment factor regardless which sector that might be in. Whilst there is some merit in this argument, taken to its extreme, it is clearly flawed as such a policy

30 Computable general equilibrium – a methodology that should explicitly take account of price effects, see Chapter 3

31 One study #55 gave employment impacts as zero because the simple CGE model used assumed the economy remained in equilibrium (i.e. full employment) under all circumstances.

would encourage spending in sectors regardless of whether or not spending was required there. Clearly, sensible fiscal policy has to take account of investment needs, not just the supply of finance. The approach taken in this review (as described above) was to take a middle ground by comparing job impacts of investment in RE and EE against traditional fossil-fuel generation. The rationale for this choice is that if investment in electricity generation is required, then the choice of generation technology may be affected at the margin by information about job creation effects.

- Authors' views on macro-economic fundamentals also tend to dominate their results. In particular, results are sensitive to assumptions about the existence of spare capacity in the economy to absorb the new jobs without 'crowding out' the benefits. A neo-Keynesian approach addresses this in terms of the 'output gap'; for example, OECD analysis indicates that aggregate demand remains below economic capacity for many countries following the post-2008 recession (see Section 2.2). This gap suggests that demand could be stimulated by encouraging additional spending without inflationary effects cancelling out the benefits. Most neo-Keynesian economists would agree that such a state of affairs would be temporary, persisting until the economy had returned to (near) equilibrium conditions, though no consensus exists over how to predict how long this period might last. Some of the simpler and more optimistic analyses ignore crowding out, and assume that gross job estimates for a particular set of investments equate to total jobs added to the economy, and that those filling these jobs can be found from the pool of unemployed without impacting on the labour market dynamics in other sectors (see review by Lesser (2010)). Other authors (e.g. Michaels and Murphy (2009), Morriss *et al.* (2009) and Hughes (2011)) emphasise the knock-on consequences for the labour market, and suggest that investment in green energy will tend to produce few if any 'new' jobs, rather they will simply re-distribute jobs within the economy. Whilst most economists might agree with this position regarding the long-run impacts on the economy, there is no clear agreement over what timescales such equilibrium effects would be expected to manifest for an economy in recession.
- Closely related to this second point is the question of dynamic efficiency. Critics such as Furchtgott-Roth (2012) and Morriss *et al.* (2009) argue that even if one can create green jobs in the short-run, is it a good thing to have high employment factors per unit of output? Does high labour intensity not simply imply an inefficient and more expensive energy sector which will be a drag on the economy in the long-term? This critique is really aimed at the rather one-dimensional nature of much of the green-jobs literature. Taken at face value, it seems a fair criticism, since much of the green jobs literature tends to ignore these long-term questions of efficiency. On the other hand, the most important dynamic efficiency benefits of green energy investments lie outside the domain of the labour market in the economics of transition towards a low carbon economy. Viewed from this angle, the disagreement between the pro- and anti- literature essentially boils down to a difference of opinion about the need for such a transition, its timing, and the role of RE. Those supporting such a transition also point to dynamic effects that could come into play, but in a positive way. Fankhauser *et al.* (2008) suggest that:

> *"In the longer term, climate change policy will unleash a wave of innovation as firms reposition themselves and seek to exploit carbon opportunities. Jobs will be created in research and the development of low-carbon technologies. Over time, the results of this research will generate new investment and further job opportunities. What these will be and how this would differ from what would have happened without these policies is hard to predict. What is not in doubt, however, is the powerful effect that innovation and technical change can have on productivity and economic growth."*

In conclusion, there is reasonable evidence from the literature that RE and EE are more labour-intensive than fossil-fired generation, both in terms of short-term construction phase jobs, and in terms of average plant lifetime jobs. Therefore, if investment in new power generation is needed, RE and EE can contribute to short-term job creation so long as the economy is experiencing an output gap, such as is the case during and shortly after recessions. However, the electricity sector is not the most labour intensive sector in the economy, so if policy is to be judged purely in terms of the number of jobs created per £ invested regardless of investment needs, other sectors such as construction may show greater job creation potential. In the long-term, if the economy is expected to return to equilibrium conditions of full employment, then 'job creation' is not a meaningful concept. In this context, high labour intensity is not in itself a desirable quality, and green jobs is not a particularly useful prism through which to view the benefits of RE and EE investment. What matters in the long-term is overall economic efficiency, taking into account environmental externalities, and the dynamics of technology development pathways. In other words, the proper domain for the debate about the long-term role of RE and EE is the wider framework of energy and environmental policy, not a narrow analysis of green job impacts.

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Appendix

A: How the Review was Conducted

The topic for this assessment was selected by the UK Energy Research Centre's Technology and Policy Assessment (TPA) Advisory Group which is comprised of senior energy experts from government, academia and the private sector. The Group's role is to ensure that the TPA function addresses policy-relevant research questions. The Group noted the persistence of controversy about this topic, the existence of widely diverging views, and the mismatch between the relative neglect of the issue and its potential importance. It was considered that a careful review of the relevant evidence could help to clarify the reasons for the diverging views, encourage more constructive dialogue between the 'opposing camps' and make the issues more accessible to a non-technical audience.

The objective was not to undertake new research on the employment impacts of investment in renewable energy and energy efficiency but instead to provide a thorough review of the current evidence (Box 1). Following this model, the assessment began with a *Scoping Note*[32] that summarised the debate on low carbon jobs and identified the potential contribution that a TPA assessment could make. This identified several sources of controversy including: the conceptual difficulties in identifying net employment impacts; the implications of differing methodological approaches; the level of uncertainty within the current evidence; and the significance of differing assumptions and perspectives within the evidence. The objectives of the assessment were designed with these issues in mind.

An expert group was established for the project consisting of stakeholders with expertise in the assessment of employment impacts and the low carbon economy (see Appendix C). The scoping note was made available for comment to this group on the UKERC website. Through this process the nature of the project was further defined.

Box 1 Overview of the TPA approach

The TPA approach is informed by a range of techniques referred to as evidence-based policy and practice, including the practice of systematic reviews. This aspires to provide more robust evidence for policymakers and practitioners, avoid duplication of research, encourage higher research standards and identify research gaps. Core features of this approach include exhaustive searching of the available literature and greater reliance upon high quality studies when drawing conclusions. Energy policy presents a number of challenges for the application of systematic reviews and the approach has been criticised for excessive methodological rigidity in some policy areas (Sorrell, 2007). UKERC has therefore set up a process that is inspired by this approach, but is not bound to any narrowly defined method or technique.

The process carried out for each assessment includes the following components:

- Publication of Scoping Note and Assessment Protocol.
- Establishment of a project team with a diversity of expertise.
- Convening an Expert Group with a diversity of opinions and perspectives.
- Stakeholder consultation.
- Systematic searches of clearly defined evidence base using keywords.
- Categorisation and assessment of evidence.
- Review and drafting of technical reports.
- Expert feedback on technical reports.
- Drafting of synthesis report.
- Peer review of final draft.

32 Available at: www.ukerc.ac.uk/support/Low+Carbon+Jobs

The assessment began with a systematic review of the literature on employment impacts and the low carbon economy. The following databases were searched:

- Cambridge Scientific Abstracts
- Elsevier "Science Direct"
- Google Scholar
- ISI "Web of Knowledge"
- Worldcat (Online Computer Library Centre, OCLC)

The following search terms were used, with at least one word from each column required in the article title, abstract or key words.

Employment	Energy and Environment	Policy
Employment	Energy*	Polic*
Job*	Environment*	Subsid*
Work*	Green	Support*
	Low carbon	Incentiv*
	Clean	
	Renewable*	
	Efficiency	
	Climate	
	Wind	

Part of the analysis in this study involves comparing green job estimates with estimates of jobs in traditional (fossil-fired) power generation. In order to reduce any bias that may arise in the 'green jobs' literature with respect to job estimates for fossil-fired technology, an additional literature search was carried out in the Elsevier "Science Direct" database using the terms shown in the table below, again with at least one word from each column required in the article title, abstract or key words. Note that in this case 'work*' was omitted because it produced a very large number of unrelated scientific papers. The policy-related search terms were omitted in order to broaden the search, and to include job estimates for the sector that arise without policy stimulus.

Employment	Energy
Employment	Coal*
Job*	Fossil
	Natural gas
	Shale gas

For both sets of searches, the results were then scanned for relevance based on the title and abstract of the publications, and categorised into two groups (with some overlap between the two groups):

A. Studies that provide methodological or conceptual insight. These comprised over 40 papers which provide the basis for the discussion sections of this review, and are included where appropriate in the references throughout the text of the report.

B. Studies that provide evidence of quantitative estimates of employment impacts for renewable energy and/or energy efficiency investment. 96 papers were selected for more detailed review, as listed in Appendix B. Of these, 59 publications provided data in a form suitable to be extracted for the quantitative analysis presented in Section 4. Where data or other insights were available in the remaining 37 papers, these have been referenced separately in the text.

All the publications from the systematic review which provided some kind of quantification of employment impacts are listed in the Appendix. The results of the second search focussed on the fossil fuel generation sources are denoted F1-F12. In total, this search resulted in 84 publications in total, which were then assessed in greater detail. Of these, 59 publications provided data in a format and in sufficient detail to allow the comparative analysis presented in Section 4. There are various reasons why not all the publications could be included in the comparative analysis, noted in the Appendix B. In terms of scope, papers relating to biofuels were excluded from the comparative analysis because of the difficulty of translating data into comparable units.

For papers which were within scope, exclusions were in some cases due to data being presented in insufficient detail; for example, not specifying the scale of the RE or EE investment, not providing enough clarity about what was covered by the financial investment, or not providing a definition of how the jobs were being measured. In other cases, good data was provided, but not in a form that could be compared directly with other papers. Where possible and appropriate, this data has been incorporated elsewhere in the text of this report. Further detail is provided in Section 4.1 on the methodology used to extract and analyse the data from these publications.

B: Publications from the review that provided quantitative estimates of employment impacts

Index No. #	Reference	Used in Quant Review	Methodology[33]	Peer Review	Job Type: D, DI, DII	Gross or Net	Technology	Reasons for exclusion from quantitative review
1	Adelaja *et al.* (2010)	Y	IO	Y	D	G	Onshore wind, solar	
2	Algoso & Willcox (2004)	N	A	N	D		Onshore wind, solar	Excluded as only includes secondary data
3	Allan *et al.* (2007b)	Y	S, IO	Y	DII	N	All incl. fossil	
4	Allan *et al.* (2011)	Y	CS, SAM	Y	DII	G	Onshore wind	
5	Allan *et al.* (2008)	Y	CGE	Y	DII	N	Marine	
6	Ases (2007)	N	S					Not enough information to calculate job factors
7	Bailie *et al.* (2001)	N	IO	N	DII	G	Multiple	Analysis of policy package incl. RE, EE, tax incentives etc. Not possible to split out
8	Barkenbus *et al.* (2006)	N	IO	N	DII		All RE	Does not allow conversion of construction jobs to annualised basis
9	Barrett and Hoerner (2002)	N	IO	N	DII		All	Shows positive employment and GDP impacts from a package of green policies including RE/EE/CAFE standards and carbon pricing. Not possible to disaggregate
10	Bergman (1988)	N	R	Y				Methodology review paper
11	Bezdek and Wendling (2005)	Y	IO	Y	DII	N	Vehicle EE	
12	Blanco and Isenhouer (2010)	N	econo-metric				Biofuel	Out of scope
13	Blanco and Rodrigues (2009)	Y	S	Y	D	G	Wind	
14	Böhringer *et al.* (2013)	N	CGE				RE	Can't calculate job factors from the data. But shows how the employment impact depends on the source of the money
15	Britz and Hertel (2009)	N	CGE	Y			biofuels	No employment analysis

33 **S**urvey, **CS** case study, **R**eview, **IO** input-output, **CGE** computable general equilibrium, **SAM** social accounting matrix, **ME** macro econometric, Other

Index No. #	Reference	Used in Quant Review	Methodology[33]	Peer Review	Job Type: D, DI, DII	Gross or Net	Technology	Reasons for exclusion from quantitative review
16	Buddelmeyer *et al.* (2008)	N	CGE	N			Climate policy	No employment analysis
17	Burnes *et al.* (2005)	N	CS	Y	D	G	biofuels	Out of scope
18	Caldés *et al.* (2009)	Y	IO, CS	Y	D, DI	G	CSP	
19	Cameron and Van der Zwaan (In Submission)	Y	R	Y	D	G	Wind, PV, CSP	
20	Carlson *et al.* (2010)	Y	IO	Y	D	G	Wind (manf. only)	
21	Chateau and Saint-Martin (2013)	N	CGE	Y		N	Carbon pricing	Mostly concerned with impacts of carbon pricing & tax, with results of revenue recycling and double dividend effects
22	Costanti (2004)	Y	IO	N	DII	G	Wind	
23	del Río and Burguillo (2009)	N	R					Review paper, mostly focused on other societal impacts
24	Deyette *et al.* (2004)	N	IO	N				Not new data
25	Dixon *et al.* (2007)	N	CGE	N	DII	N	Biofuels replacing petroleum	Out of scope
26	Etuc (2007)	N	A	N			Gen climate policy	Climate policy scenarios, cannot disaggregate RE, EE.
27	Faaij *et al.* (1998)	Y	IO	Y	D, DI	GN	Biomass replacing coal	
28	Faulin *et al.* (2006)	Y	S	Y	D	G	Wind	
29	Gohin (2008)	N	CGE	Y			Biofuels	Focussed on macro-econ impacts not jobs, also out of scope
30	Goldberg *et al.* (2004)	Y	IO	N	DII	G	Wind	
31	Groscurth *et al.* (2000)	Y	CS + IO	Y	DI	GN	Biomass vs fossil fuels	
32	Guertler *et al.* (2010)	Y	S	N	D	G	Household EE	
33	Hillebrand *et al.* (2006)	Y	IO + monetary analysis	Y	DII	N	RE	
34	Jaccard (1991)	Y	IO	Y	D, DII	N	Elec EE	
35	Kaiser *et al.* (2005)	Y	IO	Y	DII	G	Household EE	
36	Kaiser *et al.* (2004)	Y	IO	Y	DII	G	Household EE	

Index No. #	Reference	Used in Quant Review	Method-ology[33]	Peer Review	Job Type: D, DI, DII	Gross or Net	Technology	Reasons for exclusion from quantitative review
37	Kenley *et al.* (2009)	N	S, CS, IO	Y	DII		Nuclear	Out of scope
38	Krajnc and Domac (2007)	Y	Other	Y	DII	G	Biomass CHP	
39	Kuckshinrichs *et al.* (2010)	N	IO	Y			Household EE	Study focussed on social costs of carbon, comparing value of job creation vs. overtime. Not possible to calculate employment factors.
40	Kulisic *et al.* (2007)	Y	IO	Y	DI	G	Biodiesel	Out of scope
41	Laitner *et al.* (1998)	Y	IO	Y	DII	N	RE + EE combined	
42	Lantz and National Renewable Energy (2008)	Y	IO	N	D, DI	G	Wind	
43	Lantz and Tegen (2008)	Y	IO	N	DII	G	Wind	
44	Lehr (2008)	Y	S, IO, ME	Y	DII	N	All	
45	Lehr *et al.* (2012)	N	ME	Y	DII	N	RE	Doesn't separate out technologies, and cannot calculate employment factors. Useful focus on sensitivity to export markets.
46	Lenzen and Dey (2002)	Y	IO	Y	DII	N	Solar CSP	
47	Lesser (1994)	Y	IO	Y	DII	G	Geothermal	
48	Llera Sastresa *et al.* (2010)	N	R, CS	Y	DI	G	Wind, solar	Not enough information to annualise jobs info
49	Llera *et al.* (2013)	Y	S	Y			Solar PV	
50	Low and Isserman (2009)	Y	IO	Y	DII	N	Biofuels	
51	Madlener (2007)	Y	IO	Y	DII	G	Solid biomass	
52	Marsh and Miers (2011)	Y	A + IO	N	D	N	RE total	
53	Mongha *et al.* (2006)	Y	IO	N	DII	G	Wind	
54	Moreno and López (2008)	N	R, CS	Y	D	G	Multi	Review paper, not included
55	Moscovitch (1994)	Y	CGE	Y	DII	N	DSM EE	
56	Neuwahl *et al.* (2008)	N	IO + dynamic price model	Y	DII	N	Biofuels	Out of scope

Index No. #	Reference	Used in Quant Review	Methodology[33]	Peer Review	Job Type: D, DI, DII	Gross or Net	Technology	Reasons for exclusion from quantitative review
57	Ouderkirk and Pedden (2004)	Y	CS, S	N	D	G	Wind	Construction only
58	Paul *et al.* (2010)	Y	IO	Y	DII	N	End-use elec EE	
59	Marvão Pereira and Marvão Pereira (2010)	Y	Econometric VAR	Y	DII	N	EE	
60	Perez-Verdin (2008)	Y	IO	Y	DII	G	Biomass for power or biofuels	
61	Pickerill and Scott (1985)	N					H2	Out of scope
62	Pollin *et al.* (2008)	N	-					No detailed analysis
63	Pollin and Garrett-Peltier (2009)	Y	IO	N	DI	G	EE, wind, solar, smart grid	
64	Pollin *et al.* (2009)	Y	IO	N	DII	G	Fossil, RE, EE	
65	Reategui and Tegen (2008)	Y	IO	N	DII	G	Wind	
66	Rose *et al.* (1982)	R	IO	Y			Geothermal	Paper does not give useable numbers on absolute jobs
67	Ruth *et al.* (2010)	Y	IO	Y	DII	G	Domestic gas EE	
68	Scott *et al.* (2003)	N						Ignore unpublished report in favour of peer reviewed paper by same author with similar scope
69	Scott *et al.* (2004)	N						Ditto
70	Scott *et al.* (2008)	Y	IO	Y	DII	N	EE buildings	
71	Simas and Pacca (2014)	Y	S	Y	D, DI	G	Wind	
72	Sterzinger (2006)	N	R					Not a quantitative report
73	Swenson and Eathington (2006)	N						Summary of next report
74	Swenson (2006)	N	IO, CS	N	DII	G	Biofuel	Out of scope
75	Tegen *et al.* (2006)	Y	IO	N	DII	G	Coal Gas Wind	
76	Thornley *et al.* (2008)	Y	CS + multiplier	Y	DII	G	Biomass	
77	VanDyne *et al.* (1996)	N	IO	Y	DII	N	Biodiesel	Out of scope

Index No. #	Reference	Used in Quant Review	Method-ology[33]	Peer Review	Job Type: D, DI, DII	Gross or Net	Technology	Reasons for exclusion from quantitative review
78	Varma and Medhurst (2007)	Y	IO +	N	DII	N	EE	
79	Wei *et al.* (2010)	Y	R	Y	D	GN		Review paper: just include additional sources not already in this review
80	Weisbrod *et al.* (1995)	Y	S, CGE/ simula-tion	N	DII	N	EE biomass	
81	Whiteley *et al.* (2004)	Y	IO	N	DII	G	Wind, PV geothermal	
82	Wietschel and Seydel (2007)	N		Y			H2	Out of scope
83	Williams *et al.* (2008)	Y	IO + monte carlo	Y	DII	G	Wind	
84	Yi (2013)	N	Ex-post Econo-metric	Y	DII	N	RE & EE	Econometric analysis linking existence of state-level clean energy policies with overall employment levels. Not possible to construct employment factors.
F1	Black *et al.* (2003)	N	Econo-metric	Y			coal	Looks at the impact on welfare budgets of shocks to coal and steel industry. Not possible to extract employment factors
F2	Collins *et al.* (2012)	Y	IO	Y	DII	G	MTM coal	Mountain-top coal mining
F3	Dunne and Merrell (2001)	N	Econo-metric	Y				Assessing US coal mining, correlation of job creation/destruction with economic business cycles, not possible to calculate employment factors
F4	Fernández (2000)	N	Partial equil	Y			Coal	Looks at policy cost of protecting coal mining jobs in Spain. Not possible to extract employment factors
F5	IHS Global Insight (2011)	Y	IO	N	DII	G	Shale gas	
F6	Kinnaman (2011)	N	R	Y			Shale gas	Not possible to extract employment factors from the review. Generally critical of the methodologies used.
F7	Lund *et al.* (2003)	N	CS	Y				Source of data and employment assumptions not clear

Index No. #	Reference	Used in Quant Review	Method-ology[33]	Peer Review	Job Type: D, DI, DII	Gross or Net	Technology	Reasons for exclusion from quantitative review
F8	Qi *et al.* (2012)	N		Y			Coal to liquids	Out of scope
F9	Tourkolias *et al.* (2009)	Y	IO + CS	Y	DII	G	Coal, gas	
F10	Wang *et al.* (2014)	N		Y			Shale gas	Job estimates derived from IHS (study #F5) already included
F11	Weber (2012)	N					Shale gas	Results consistent with and updated by Weber 2013 (below)
F12	Weber (2013)	Y	Econo-metric	Y	DII	N	Shale gas	

C: Expert Group, Peer Reviewers and acknowledgements

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Acknowledgements

The authors are very grateful for the input from the expert group members in the early stages of the project, and for comments from the peer reviewers on the final draft. We are also grateful to Matthew Aylott of UKERC for copy editing. Responsibility for the content of this report and any errors and omissions rests solely with the authors.

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