Low carbon jobs: the evidence for net job creation from policy support for energy efficiency and renewable energy

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Abstract

The focus of this paper is whether 'green' policies lead to the creation of additional jobs. To avoid controversies around definitional issues, the paper focuses on a relatively narrow subset of 'green' policies, namely support for renewable energy (RE) and energy efficiency (EE).

The research question that this paper addresses 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 assessment is based on a systematic review of the literature on employment impacts and the low carbon economy, including a comparison of green job estimates with estimates of jobs in traditional (fossil-fired) power generation.

Evidence from the literature suggests a reasonable degree of confidence in the conclusion that RE and EE are more labour intensive in terms of electricity generated or saved than traditional fossil-fuel generation. The quality of gross jobs estimates varies, but many studies are robust, involving substantial surveys of the relevant industries. Overall, the evidence therefore points towards the potential for RE and EE to be able to create jobs in the short-term under conditions of suppressed aggregate demand (such as during or post-recession).

However, in the longer-term the effect on energy prices and household expenditures needs to be taken into account. There are many fewer macro-economic studies of jobs impacts of RE and EE, and they show more mixed results. Some studies using computable general equilibrium models indicate positive employment impacts, some negative, whilst others show positive impacts during the early stages of project development, transitioning to negative impacts at later periods once price effects have filtered through.

In the long-term, 'job creation' ceases to be a meaningful concept if economies are assumed to migrate towards equilibrium conditions. A more important consideration for RE policy is their impact on dynamic economic efficiency. A high labour intensity is not an advantage in this regard since it implies low labour productivity. However, the main dynamic benefits of renewable energy do not lie in the domain of employment policy, but in the domain of energy policy, namely their role in the transition to a low-carbon energy system. This points to the limitations of using the green jobs debate as a vehicle for discussing the long-term role of RE in the energy system.

This paper is based on work carried out by the UK Energy Research Centre's (UKERC) Technology and Policy Assessment (TPA) team, funded through the Research Councils UK Energy Programme.

1 Overview

1.1 Introduction

The focus of this paper is a contentious strand to the green jobs debate, namely: are there, as some proponents claim, benefits to employment from clean technologies that arise *irrespective* of their environmental case? (Pollin *et al.*, 2009, UNEP, 2008, Bezdek, 2009) Some critics suggest that the imposition of more expensive technologies will, overall, tend to be economically damaging (Huntington, 2009, Morriss *et al.*, 2009, Michaels and Murphy, 2009). The issue we address here is whether 'green' policies lead to the creation of additional jobs. To avoid controversies around definitional issues, the paper focuses on a relatively narrow subset of 'green' policies, namely support for renewable energy (RE) and energy efficiency (EE).

The specific research question that this paper addresses 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 paper focuses on OECD countries, reflecting the nature of the evidence base. We consider Full Time Equivalent (FTE) jobs as this is standard within the literature. We exclude policies which use carbon pricing from the paper because the economic impact of these mechanisms is well understood and comprehensive reviews of this literature have been published previously. This paper focuses instead on other forms of support, including subsidies, efficiency standards, and feed-in tariffs.

The literature can broadly be divided into two branches. The first branch is what might be considered dedicated 'green jobs' literature, with the second being the broader macro-economic perspectives on employment. The former is essentially based on a 'job counting' approach, attempting to quantify how many jobs are created by investments in RE and EE. The latter takes an economy-wide perspective from the outset, addressing the wider labour market impacts of green policies.

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

1.2.1 'Gross' vs. 'Net'

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. Equally relevant however 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. For example, several studies (Allan et al., 2007, Groscurth et al., 2000, Lenzen and Dey, 2002, Wei et al., 2010) offset the number of gross jobs created through additional RE by the implied number of jobs that would be lost in other parts of the power sector.

1.2.2 Direct, indirect and induced

An important issue to address is how far analysis should include the economic 'ripples' of investment in creating indirect and induced jobs? Direct employment refers to those jobs that that arise directly as a result of the investment, and indirect employment commonly refers to the jobs created within the supply chain supporting a specific project. Induced employment typically refers to jobs created as a result of the increased household expenditure of direct and indirect employees. Displaced employment refers to those jobs lost in (for example) the fossil-fired power stations that no longer need to be operated or built as a result of the RE or EE investment.

The factor by which indirect or induced jobs increase for a given increase in direct jobs is the multiplier, 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 1.

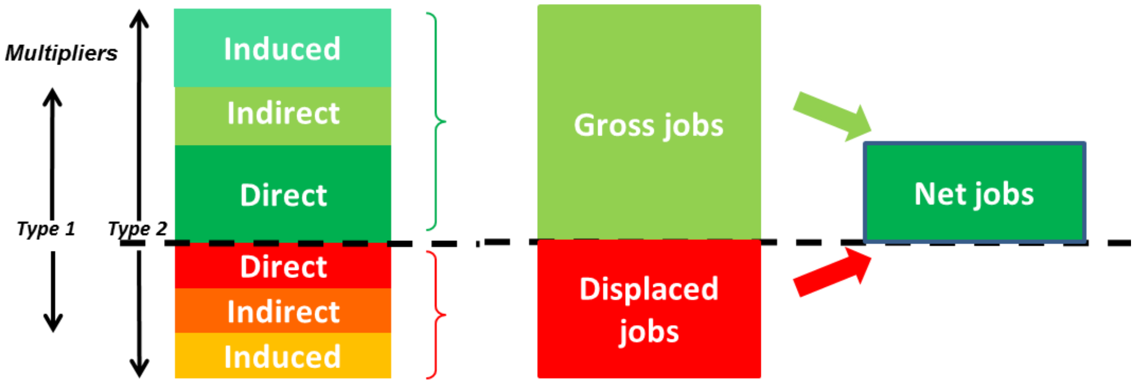

Figure 1 Schematic showing the relationship between different types of job impact, showing for illustrative purposes a positive net impact (negative net job impacts are also possible depending on the scale of displaced jobs)

1.2.3 Opportunity costs and counterfactuals

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*. By contrast, green job sceptics focus more strongly on opportunity costs and the counterfactual, 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.

1.2.4 Job length and quality

Jobs associated with a particular investment may be full-time or part-time, and may last anywhere from a few months to many years. 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.* (Wei et al., 2010), (Lantz and National Renewable Energy, 2008)). 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 paper, 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.

1.2.5 Measurement metrics

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'.

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.

1.2.6 Macroeconomic analyses

Macroeconomic analyses are usually 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, solving some of the short-comings of the 'job counting' approach identified above. 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 the rest of the economy. However, any attempt to model employment impacts has to make some fundamental and contested assumptions about interactions between the labour market and the wider economy.

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 – and such conditions are much harder to model.

2 Methodology

The research on which this paper is based was conducted by the UK Energy Research Centre's Technology and Policy Assessment (TPA) team. Following the normal approach for TPA projects, the assessment began with a *Scoping Note*[1] 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 assessment began with a systematic review of the literature on employment impacts and the low carbon economy, including a comparison of green job estimates with estimates of jobs in traditional (fossil-fired) power generation. The results of the systematic review 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 and are included where appropriate in the references throughout the text of the paper.
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 the Annex. Of these, 59 publications provided data in a form suitable to be extracted for quantitative analysis. Where data or other insights were available in the remaining papers, these are cited in the text.

Papers relating to biofuels were excluded from the comparative analysis because of the difficulty of translating data into comparable units. Other 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, data was not in a form that could be compared directly with other papers. Details of the publications reviewed are available in the Annex (to which the identification numbers below refer) and will also be available on the project webpage (see footnote) when the full TPA project report is completed. Thirty four papers were excluded from the quantitative analysis for one or more of the following reasons:

- 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)

[1] Available at: www.ukerc.ac.uk/support/Low+Carbon+Jobs

- 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). These are discussed separately at the end of the results section.

3 Results

3.1 Introduction

This section summaries the results from the comparative analysis of the studies revealed by the literature review. The focus is on comparison across technologies and between long-term and short-term impacts. Full details of the detailed technology-specific analysis will be available on the project webpage[2] when the main project report is completed.

3.1.1 Gross and Net Employment Impacts

The majority of the publications reviewed provided only the gross jobs impacts of RE and EE investments, 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. This allowed approximate estimates of net job impacts to be derived by comparing gross jobs estimates between RE and EE versus fossil fuel, albeit with the following caveats:

- 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 they may impose additional system costs, 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 only in macroeconomic studies.

Given that both positive and negative effects may be excluded, it is not obvious *a priori* that there are biases in any particular direction.

In the results presented from publications which report net job impacts, the job impacts of RE or EE investments have already been netted off against a counterfactual, usually a fossil-fuel related investment. However, the degree to which these analyses address the wider system 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.

[2] Available at: www.ukerc.ac.uk/support/Low+Carbon+Jobs

3.1.2 Calculating Employment Factors

In this paper, each job is taken to represent a FTE job which lasts for the anticipated duration of the plant in question, so jobs numbers relating to the manufacturing and construction phase need to be spread over 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). 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 although . 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 the 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 load factor for each technology. Where these were not stated in the publications, the following assumptions were made:

Technology	Average annual load factor
Wind (Onshore)	30%
Wind (Offshore)	35%
Solar PV	30%
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.

3.2 Gross Jobs Summary

The gross number of jobs created per unit of electricity generated is shown in Figure 2 for different generation technologies. This figure 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 2 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 2 do not necessarily follow this expected pattern because they aggregate different data sets.

Figure 2 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.

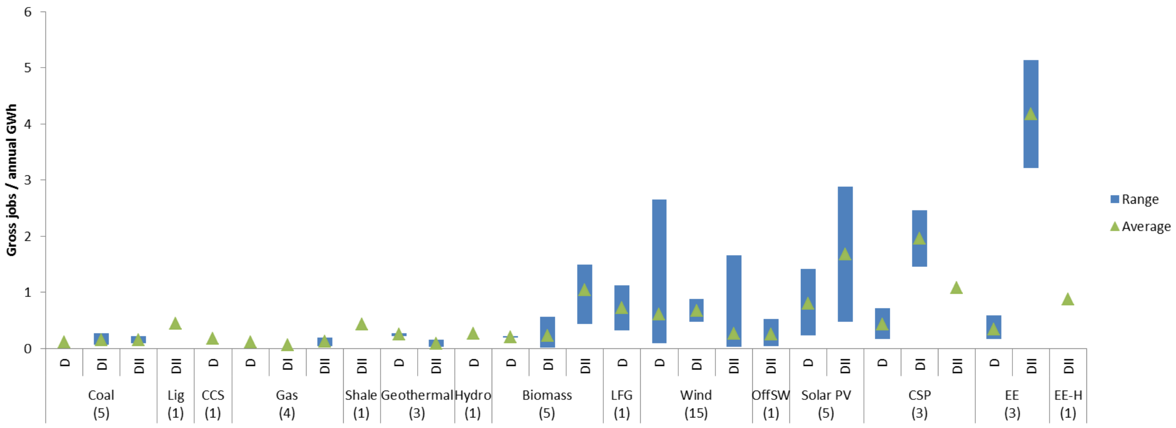

Figure 2 Gross jobs per annual GWh generated[3] (number of studies in brackets)

Figure 2 also suggests some 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.

Figure 3 shows the employment impacts using a financial indicator, in terms of jobs/£m invested. 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 3 compared to Figure 2 (although note again that the two charts are not aggregating the same set of literature, which will account for some of the differences).

[3] The following abbreviations key is used for the results charts in this paper - 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.

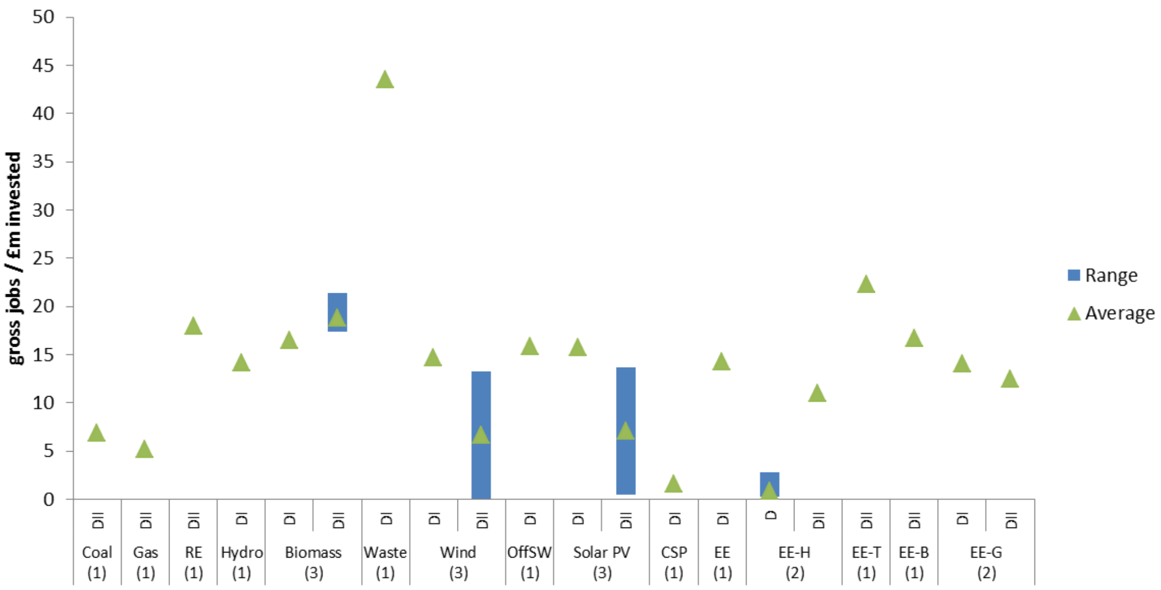

Figure 3 Gross jobs per £m invested[4] (number of studies in brackets)

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. 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).

3.2.1 Short-term construction and installation jobs

The analysis in the previous section is concerned with a comparison of total jobs estimates, where short-term and long-term jobs have been combined. However, if the focus of policy is on rapid economic stimulus, then it is the short-term jobs impacts which are of particular 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 4, with average values across the ranges shown in Table 1. 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.

[4] See footnote to Figure 2 for abbreviations key.

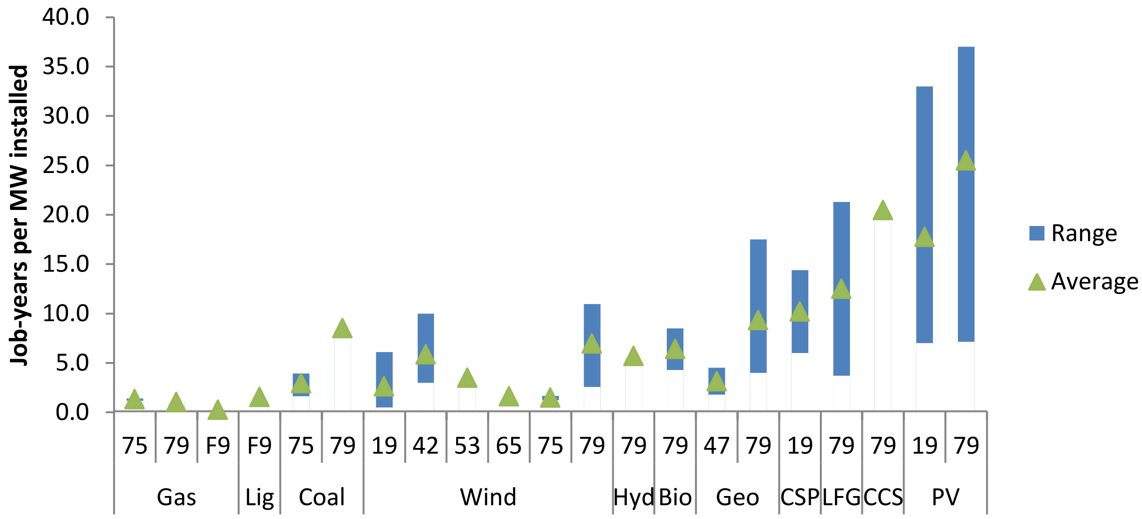

Figure 4 Short-term direct jobs during the construction phase of projects[5]

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

Table 1 Average short-term direct jobs during construction period

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 load factors for intermittent RE, especially wind and solar. If the units were

[5] See footnote to Figure 2 for abbreviations.

changed to compare projects on the basis of average load factor, 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.

3.3 Net Jobs Summary

Figure 5 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 positive. 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.

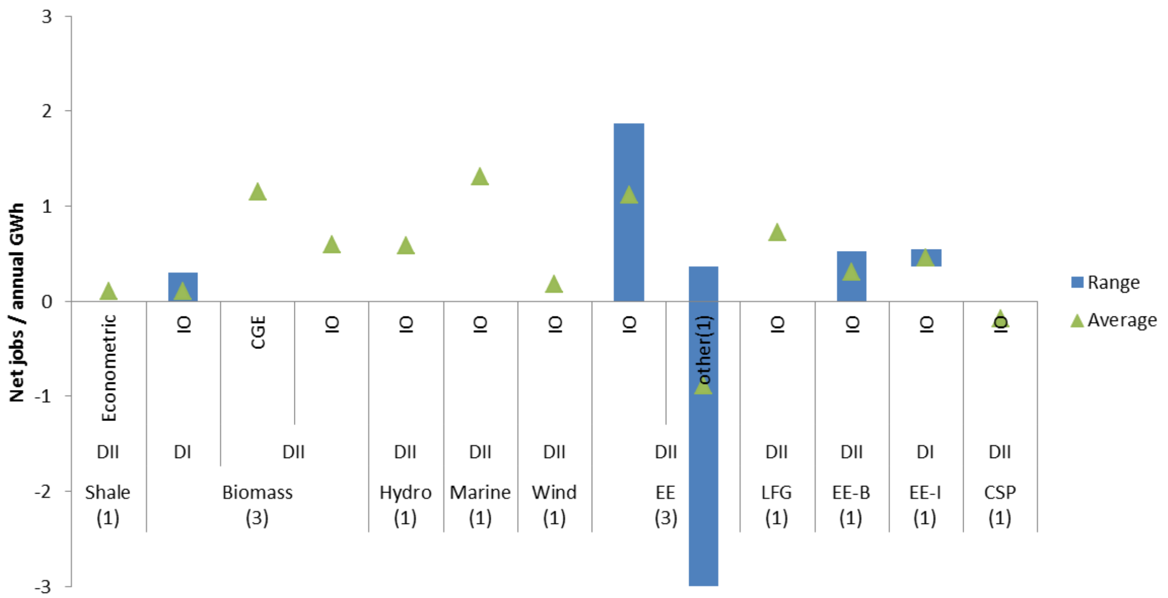

Figure 5 Net jobs per annual GWh generated[6] (number of studies in brackets)

Net jobs estimates based on the financial indicator of jobs/£m invested are summarised in Figure 6. 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.

[6] See footnote to Figure 2 for abbreviations key.

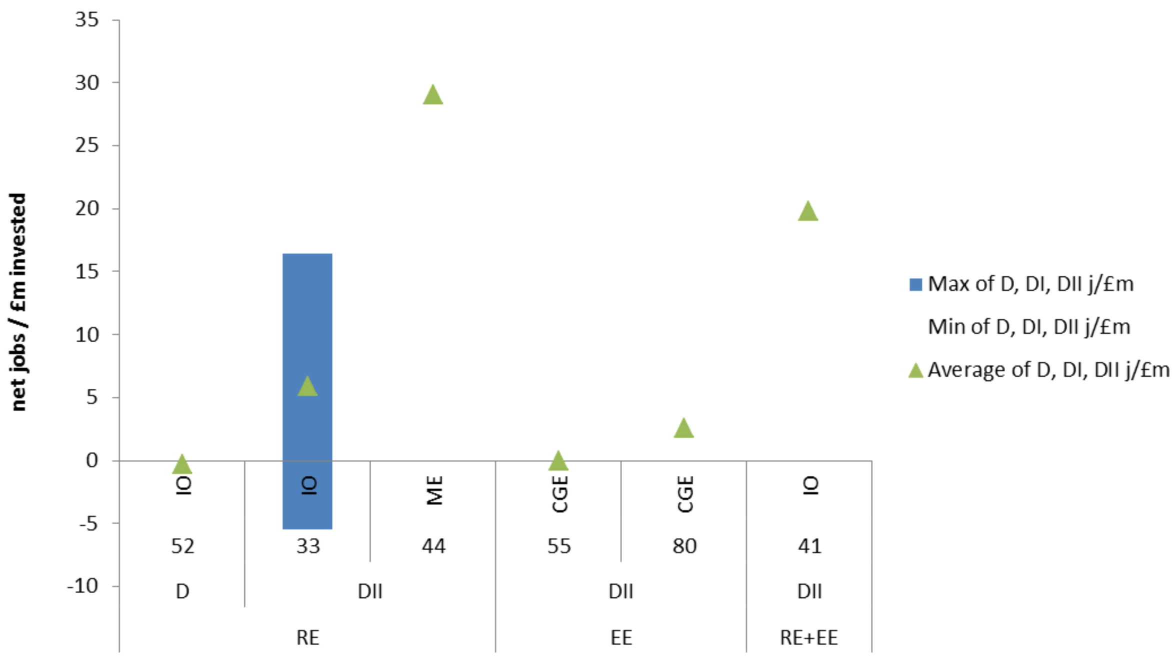

Figure 6 Net jobs per £m invested[7]

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 compare 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,

[7] Numbers in the x-axis refer to publication index numbers from the Annex, See footnote to Figure 2 for abbreviations key.

the labour impacts of RE are smaller, and could go negative under a minimal exports scenario (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.

3.4 General Equilibrium Studies

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 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. Study #80 for biomass gave relatively high employment factors when compared to other studies. 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, such as technology, labour market conditions, and price assumptions.

The results of Study #14 (Böhringer et al., 2013) provide an important supplement to the results derived from IO models presented above. Their 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, their 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.

4 Summary and Conclusions

4.1 Quantitative analysis

The 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. Whilst methodologically simple and having the largest data-set on which to base the analysis, the disadvantage of this approach is that it excludes the effect on electricity prices, and also requires comparing results between different publications which may have used different (possibly incompatible) assumptions and methodologies. 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 and 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. Nevertheless, 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. Three studies calculated negative net impacts, either because of comparison with more labour intensive alternative investments, or because of the particular methodological approach taken. 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 (and therefore the wider economy) was assessed, and here the results were quite mixed. A study which explicitly extended the Input-Output 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 studies for which employment factors could be derived, all showed positive employment impacts, whilst another noted that the employment impacts of RE 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.

4.2 Other findings

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 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. Whilst this assumption is clearly inappropriate, 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) (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. Taken to its extreme, such a policy 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.

Results are also sensitive to assumptions about the existence of spare capacity in the economy to absorb the new jobs without 'crowding out' the benefits. If an 'output gap' is assumed to exist, then 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)). 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? 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 perspective, 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.

4.3 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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6 Keyword set

Energy Policy

Energy Economics

Renewables

Energy Efficiency

Annex

Publications from the review that provided quantitative estimates of employment impacts

ID no #	Reference	Used in Quant Review?	Method-ology[8]	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 et al., 2004)	N	A	N	D		Onshore wind, solar	Excluded as only includes secondary data
3	(Allan et al., 2007)	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,	N	econometric				Biofuel	Out of scope

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

	2010)							
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
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)	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	
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	N	R, CS	Y	D	G	Multi	Review paper, not

	López, 2008)							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
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					H_2	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 et al., 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	N	IO	Y	DII	N	Biodiesel	Out of scope

	al., 1996)							
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/ simulation	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-poste Econometric	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	Econometric	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	Econometric	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.,	N	CS	Y				Source of data and

	2003)							employment assumptions not clear
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 2014 (below)
F12	(Weber) (2014)	Y	Econometric	Y	DII	N	Shale gas	

General equilibrium studies

Id no	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