UK Energy Research Centre

Green job creation, quality and skills: A review of the evidence on low carbon energy

UKERC Technology and Policy Assessment

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Summary

In this report we present findings from a systematic review of international literature on low carbon job creation, quality, and skills. This briefing provides an update to a 2014 UKERC report that examined the evidence for net job creation from policy support for 'low carbon jobs' (Blyth et.al., 2014). The net employment impacts of a renewable energy or energy efficiency investment account both for jobs that are created, as well as jobs that might be displaced in other parts of the economy as a result of the investment. For example, the number of gross jobs created through additional renewable energy deployment could be offset by the implied number of jobs that would be lost due to less power generation from gas and coal. This project therefore addresses the following research question:

How many jobs can be created by policy support for investment in low carbon energy and energy efficiency, compared to supporting fossil fuel incumbents?

Our review identifies a variety of approaches used to estimate the quantity of low carbon energy job creation. We find that much greater standardisation of methods would be desirable in order to compare how many jobs can be created by policies supporting low carbon energy and energy efficiency, both at a project scale and a wider societal level. Our findings also underline a relative paucity of metrics and data measuring quality, skills, and geographic distribution aspects of low carbon energy job creation, and these should be priority areas for further research.

Key findings:

Low carbon job creation

- We compare a range of recent job creation estimates which indicate that overall, policy support for, and investment in, low carbon energy (including renewables) and energy efficiency can deliver more jobs than gas or coal power generation.
- This finding is consistently supported across a range of different job creation metrics and when focusing on different technology life stages, i.e. manufacturing, installation, operation and maintenance.
- Policies supporting manufacturing and installation of renewable energy may be particularly effective at creating short-term jobs and economic stimulus. In the current context of supporting economic recovery from COVID-19, domestic construction projects such as insulation retrofits or building wind turbines could be particularly favourable and less prone to offshoring services overseas.
- There is a debate in the literature around the extent to which policies supporting renewable energy may contribute to longer term economic growth, notwithstanding short-term employment and growth benefits. Jobs created per unit of investment represent only one aspect of a low carbon transition; what matters in the longer-term is whether the investment contributes to an economically efficient transition towards a country's strategic goals, considering environmental impacts and energy security.

- We find limited evidence identifying where the benefits of potential net job creation in renewables and energy efficiency may accrue, i.e. internationally, nationally, and regionally. Demand for renewable energy construction/ installation and operation/ servicing jobs is generally created locally or within countries. However, a key uncertainty is the extent to which labour and supply chain services may be imported from other countries.
- The creation of manufacturing jobs depends upon the local or national presence of a manufacturing base in renewables or policies to develop such a capacity. Many construction/ installation and operation/ maintenance jobs may effectively be exported overseas depending on the development and size of an export market for manufactured renewables.

Quality of green jobs

- In our review of the literature, we have identified a subset of studies which discuss the quality of green or low carbon energy jobs in qualitative terms. We found a limited number of studies which use quantitative metrics to assess employment quality or relative skill levels of low carbon energy compared to high carbon energy sectors.
- It is desirable that a low carbon transition should create quality jobs, which are characterised in the literature in terms of adequate wages and employee rights, full-time employment, safe working conditions, and permanent rather than temporary jobs.
- Direct employment in renewable energy manufacturing, construction or installation has been linked to temporary or short-term work which expires on completion of specific projects or might no longer be needed once renewable energy capacity targets have been met. However, meeting the UK's net zero target implies a continuous need for manufacturing and construction jobs over several decades to build the new renewables capacity required to meet likely greater demands for electricity from heat and transport decarbonisation.
- Employment in the operation and maintenance of power generating technologies is typically more permanent, lasting over technology lifetimes.
- There is also a need for a new nationwide programme of energy efficiency and heat decarbonisation retrofitting in UK buildings which could help to stimulate ongoing, countrywide demand for low carbon jobs over several decades.

Green skills

- Various literature suggests that green jobs in general tend to be more highly skilled compared to higher carbon occupations.
- Our review reveals that renewable energy or energy efficiency jobs are not necessarily more skilled than jobs in higher carbon energy sectors. Most jobs in the operation and maintenance of wind power and solar PV are in highly skilled, professional occupations. However, there is also demand for lower-skilled, manual occupations which comprise much of solar PV installation and offshore wind construction activities.
- There is a need to co-ordinate the development and supply of training so that it takes full account of the wide range of occupational functions required for manufacturing, construction and installation, and operation and maintenance of renewable energy technologies and infrastructure.
- Green skills supply and demand, including access to and provision of training and apprenticeships, will need to be carefully co-ordinated with policies supporting green job creation. Sequential planning will be required to train and coordinate local workforces required for renewables expansion, minimising time gaps between projects and the need for construction workers to relocate.
- There is some evidence to indicate that women are underrepresented in green jobs occupations and training programmes relative to men. Therefore, access of underrepresented demographic groups to training and employment opportunities needs to be improved, and such groups should be encouraged proactively to take up careers in low carbon sectors.

1. Introduction

1.1. Context

This policy brief presents updated research building on a previous UKERC review examining the evidence for net job creation from policy support for 'low carbon jobs' (Blyth et al., 2014). Our latest analysis considers the question of whether policy-driven expansion of low carbon energy actually creates jobs, particularly if the policies in question require subsidies that are paid for through bills or taxes.

Employment and economic benefits are often cited as part of efforts to lobby for investment in clean energy projects such as renewables, low carbon heating and energy efficiency (EEIG, 2020; Beyond2050, 2022; McPhee, 2020). Such claims are often backed up by project or sector specific analyses. However historically, other literature has been more sceptical, claiming that any intervention that raises costs in the energy sector will have an adverse impact on the economy as a whole (Huntington, 2009; Michaels and Murphy, 2009; Morriss et al., 2009). The impact of energy prices on the cost of living is a key current concern given recent gas and electricity price spikes (Fernández Alvarez and Molnar, 2021). Another significant change since the previous UKERC review in 2014 is the rapid reduction in costs of leading renewable energy technologies (IRENA, 2020; Jansen et al., 2020), changing the economic context that the project is exploring.

Given the UK net zero emissions target and the economic implications of the COVID-19 pandemic, a key question is whether investment in the low carbon transition can contribute to post-COVID-19 economic growth (Figueres and Zycher, 2020; Gross, 2020b). There have been a plethora of calls for investment in green jobs, skills and infrastructure to help kickstart and consolidate economic recovery from COVID-19, in a way that is compatible with achieving net zero emissions and a societally just transition (Allan et al., 2020; CCC, 2020; EEIG, 2020; Jung and Murphy, 2020; Webb, Emden and Murphy, 2020). In their 2020 Progress Report to Parliament, the Climate Change Committee highlight several priority areas for post COVID-19 investment which include low-carbon and climate-resilient infrastructure, reskilling and retraining for a net zero and climate resilient economy, and low carbon retrofitting and future proofing of buildings (CCC, 2020). The UK government's Net Zero Strategy sets out an ambition for investment to support up to 440,000 jobs in 2030 across net zero industries (HM Government, 2021).

The purpose of this report is to set out the key findings and policy recommendations arising from the UKERC's latest project on low carbon energy jobs. Preliminary findings from the project informed the Environmental Audit Committee inquiry into Green Jobs (EAC, 2021), and were also cited in the report of the Green Jobs Taskforce convened by BEIS and DfE (Green Jobs Taskforce, 2021).

1.2. Research scope and aims

The UKERC Technology and Policy Assessment (TPA) approach learns from the practice of systematic review, which aspires to provide more robust evidence for policymakers and practitioners, avoid duplication of research, encourage higher research standards, and identify research gaps. As part of this process, the project team has engaged with a small group of expert advisers who have brought their experience and perspectives to bear on the research topic. Further details on the TPA process and expert advisers are set out in the Appendix.

There are various definitions of green jobs, and while it is important to clarify the scope of our present work in relation to these, we do not set out to contribute further to the existing definitional debate. We note for example that the Green Jobs Taskforce consider a green job as "*employment in an activity that directly contributes to - or indirectly supports - the achievement of the UK's net zero emissions target and other environmental goals, such as nature restoration and mitigation against climate risks*" (Green Jobs Taskforce, 2021, p. 15). Green jobs may vary in 'greenness', for example in terms of the proportion of tasks carried out on 'green' or 'non-green' activities (Bowen, Kuralbayeva and Tipoe, 2018). Definitions of green jobs (e.g. International Labour Organization, 2018) may also include a quality aspect, suggesting that green employment needs to be characterised by 'decent' work or good quality jobs, e.g. in terms of adequate salaries and safe working conditions (Office for National Statistics, 2021b).

For the practical purposes of carrying out a systematic review with a manageable scope, we focus specifically on renewable energy, energy efficiency and end use energy demand sectors rather than applying a wider definition of green employment. We consider the quality aspects and skill levels of jobs created in these sectors and the geographic distribution of low carbon energy employment, which could contribute to achieving a just transition.

A key definitional issue relevant to this project is the distinction between 'gross' and 'net' jobs. Gross effects include only the positive impact on employment which may be associated with a particular investment. Gross jobs can in general be created when money is spent on projects that require manufacturing, installation, operation, and maintenance of new equipment. Net employment impacts also account for jobs that might be displaced in other parts of the economy as a result of the investment. For example, net employment impacts could be the number of gross jobs created through additional renewable energy deployment, offset by the implied number of gross jobs lost in other parts of the power sector due to less power generation needed from gas and coal generation (Blyth et *al.*, 2014).

In our review, most of the identified studies quantifying job creation by technology estimated gross employment. Therefore, following an approach taken by Blyth et *al.* (2014), we provide an approximate assessment of net jobs impacts by comparing gross employment factors for renewable energy and energy efficiency with those for fossil fuels.

The overarching research question which this project addresses is:

How many jobs can be created by policy support for investment in low carbon energy and energy efficiency compared to supporting fossil fuel incumbents?

As part of this, the project team have considered the following research sub-questions:

- Quantity of jobs created
  - Which metrics have been used to quantify job creation in low carbon energy (including renewables and nuclear), energy efficiency, and fossil fuel generation?
  - How do the results of these studies compare, in relation to different units of analysis and life stages of technologies (e.g. manufacturing, installation, operation and maintenance)?
- Quality of jobs created and skills
  - What are the implications of low carbon job creation policies for the quality of jobs created?
  - Which metrics have been used to assess quality and skill levels of low carbon job creation?
- Regional / local job creation
  - Are there relevant metrics and evidence in the literature on low carbon job creation at a local / regional level, and impacts on local economies?

The following section outlines our approach to addressing these research questions, and includes several observations on the measurement of low carbon job creation.

2. Approach and evidence base

2.1. Systematic review approach

The focus of the evidence review is on renewable energy, energy efficiency and end use energy demand sectors. The geographical coverage is international but limited to evidence available in English. For the systematic review, we selected a range of key words or phrases related to: job creation; energy technologies, fuel sources and energy efficiency; policies and financial incentives; quality and skill levels of jobs created and their geographic distribution. The search terms were developed based on those used in the 2014 TPA review on green jobs and our own initial, scoping review of the literature. Search terms were combined in search strings and applied to two databases: Google Scholar and Science Direct. The searches were restricted to the years 2014 to 2021 in order to provide an update to the 2014 review. Returned results were filtered manually for relevance to the research questions based on their title and abstract, or further inspection of the main text if needed. The findings presented in this report are based on an analysis of 145 of the most relevant documents, drawn from a wider body of 359 potentially relevant documents identified through the search strategy.

2.2. How job creation is measured

Methods for estimating low carbon job creation can vary from literature reviews to calculating employment factors,[1] collation of data and statistical analysis, to several different types of modelling including statistical (e.g. regression) models, input-output models, or computable general equilibrium (CGE) models and macroeconomic or macroeconometric models. For a detailed discussion of terminology and the different methodologies used to estimate job creation, see Blyth et.*al.* (2014).

Relevant studies identified often include not just direct employment impacts, but also the wider ripple-through indirect effects of increased demand in the supply chain. Some analyses also account for the induced effect of higher spending potential for those households that have benefitted from the higher employment rates. Direct employment refers to those jobs that arise directly as a result of an 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.

In our review, we attempt to compare a range of studies which estimate employment factors for gross job creation relating to different types of renewable energy, energy efficiency, and fossil fuel generation. We compare employment factors which normalise the quantity of job creation according to the scale of activity, e.g. GW installed or level of investment. The results of these comparisons are presented in Section 3. A more limited body of the literature identified considers quality and relative skill levels of low carbon energy jobs (e.g. in relation to employment in fossil fuel industries). Such studies may be based upon analyses of employment surveys or occupational profiles derived from input-output tables, and we discuss examples in Section 4.

1 Defined by Cameron and Van Der Zwaan (2015, p. 161) as "the number of jobs derived from a certain renewable technology investment or capacity".

3. Findings on quantity of job creation

Across the most relevant documents identified in our review, there was a considerable range of issues covered including the role of policies in green job creation and recovery from economic recession, the nature (and quality) of green jobs, demographics of green workers, opportunities for youth employment, implications for green skills, and locational aspects. In this section, we review findings and quantitative metrics from the literature as they relate to how many jobs can be created in renewable energy and energy efficiency sectors compared to fossil fuel energy production and consumption. We further consider the geographic distribution and economic impact of such job creation.

3.1 How many jobs can be created in renewables and energy efficiency?

A subset of analyses focus on how a transition to renewable energy from conventional, higher carbon power generation, might affect the number of jobs created in an economy. These analyses indicate that overall, a shift to renewable energy generation from fossil-fuel based or nuclear sources may deliver an increase in jobs, on both a gross and net basis (e.g. Arvanitopoulos and Agnolucci, 2020; Cameron and Van Der Zwaan, 2015; Fragkos and Paroussos, 2018: Ram, Aghahosseini and Breyer, 2020). Furthermore, whilst some of these additional jobs are relatively short term since they relate to the construction and installation phase, Arvanitopoulos and Agnolucci (2020) found that in the UK, there is still an increase in overall jobs in the long term.

We identified 17 studies which normalise numbers of gross jobs created for different power generation technologies by the annual amount of electricity generated in GWh. However, since these studies count the number of jobs in different ways (e.g. total cumulative jobs, annual jobs created or job-years), it is not possible to compare estimates of jobs/GWh directly based on the literature. Several studies extracted from our review quantify job creation more precisely in units of job-years per GWh. According to this metric, a well cited literature review of direct, indirect and induced employment factors over technology lifetimes in the US and Europe (Wei, Patadia and Kammen, 2010) indicates high job creation potential for solar PV at 0.87 job-years/annual GWh, compared to 0.17 and 0.14 job-years/annual GWh for wind and nuclear power respectively, and 0.11 job-years/annual GWh for natural gas and coal generation. The 'equivalent' value for energy efficiency is 0.38 job-years/annual GWh saved (Ibid.). Conversely, a separate study of direct and indirect employment in Turkey (Atilgan and Azapagic, 2016) found relatively high employment factors for wind and coal power (0.49 and 0.45 job-years/annual GWh respectively), compared to 0.2 job-years/annual GWh for gas generation.

An input-output modelling analysis by Tourkolias and Mirasgedis (2011) captures direct, indirect and induced employment in Greece and attributes particularly high rates of job creation per GWh for solar PV to its low load factor (relative to other power generation technologies). The authors also find that most employment for solar PV and wind generation is created during their construction (rather than operation) phase, whereas biomass, hydro and geothermal have higher job-year/GWh rates during operation compared to construction (Ibid.).

In Figures 1a and b, we have collated data on job creation per installed capacity for different life stages of electricity generation technologies: manufacturing (in job-years/GW); construction and installation (in job-years/GW); and operation and maintenance (in jobs/GW). One job-year is one full-time job for one person lasting for a year (Dufo-López, Cristóbal-Monreal and Yusta, 2016). These units show the number of jobs created annually and are used to characterise manufacturing and construction/ installation jobs which are required in the first few years of projects and at a project-level tend to be shorter-term in nature compared to ongoing employment in operation/ maintenance. Operation and maintenance jobs are typically expressed in jobs/MW, as it is assumed that these jobs are more permanent in nature and should last over the lifetime of energy technologies (Ram et *al.*, 2022). These more granular estimates broken down by technology life stage are only available in a limited range of studies in the literature. In Figures 1a and b, we have converted jobs and job-years from the original datasets so they are normalised by GW rather than MW. This helps to aid comparison of the potential volume of jobs created by technology.

A number of key observations can be made with respect to this dataset. Firstly, there is a higher level of manufacturing job creation per GW for several types of renewables (including offshore wind, small hydro and solar PV) compared to gas or coal-fired electricity generation (Figure 1a). The average estimate of job-years created per unit of installed capacity is particularly high for offshore wind (16,800 job-years per GW). The potential to make use of high employment factors for manufacturing depends on the presence of a renewables manufacturing base in any given country. Moreover, many construction/installation and operation/maintenance jobs may effectively be exported overseas depending on the development and size of an export market for manufactured renewables. Simas and Pacca (2014) observe that the standard metric of manufacturing job-years/unit of installed capacity in a particular year may be misleading since it does not account for the proportion of imports or exports. It would therefore be possible for a country to have a very high index if installed capacity is low due to most manufactured technologies being exported.

The evidence on construction and installation (Figure 1a) indicates that this activity creates the most jobs for solar PV, biomass and small hydro, between around 15,000 and 18,000 job-years per GW. Construction of natural gas power plants is associated with the lowest level of employment (2,500 job-years per GW). Wind farm installation performs relatively modestly (averaging 4,200 and 7,200 job-years per GW for onshore wind and offshore wind respectively). Ram et.*al.* (2022) observe that demand for construction, installation, and operation and maintenance jobs tends to be created locally, and these activities are therefore a fairly good indication of the potential to generate jobs within a country or region. However, a key uncertainty is the extent to which labour and supply chain services may be imported from other countries.

Figure 1b suggests that operation and maintenance is associated with the highest number of jobs over technology lifetimes for small hydro (1,600 jobs/GW) and biomass (1,100 jobs/GW). Natural gas and coal have the lowest employment factors for operation and maintenance (130 and 155 jobs/GW respectively).

Figure 1a. Gross job-years created in manufacturing (M) and construction and installation (C&I) per GW of installed capacity

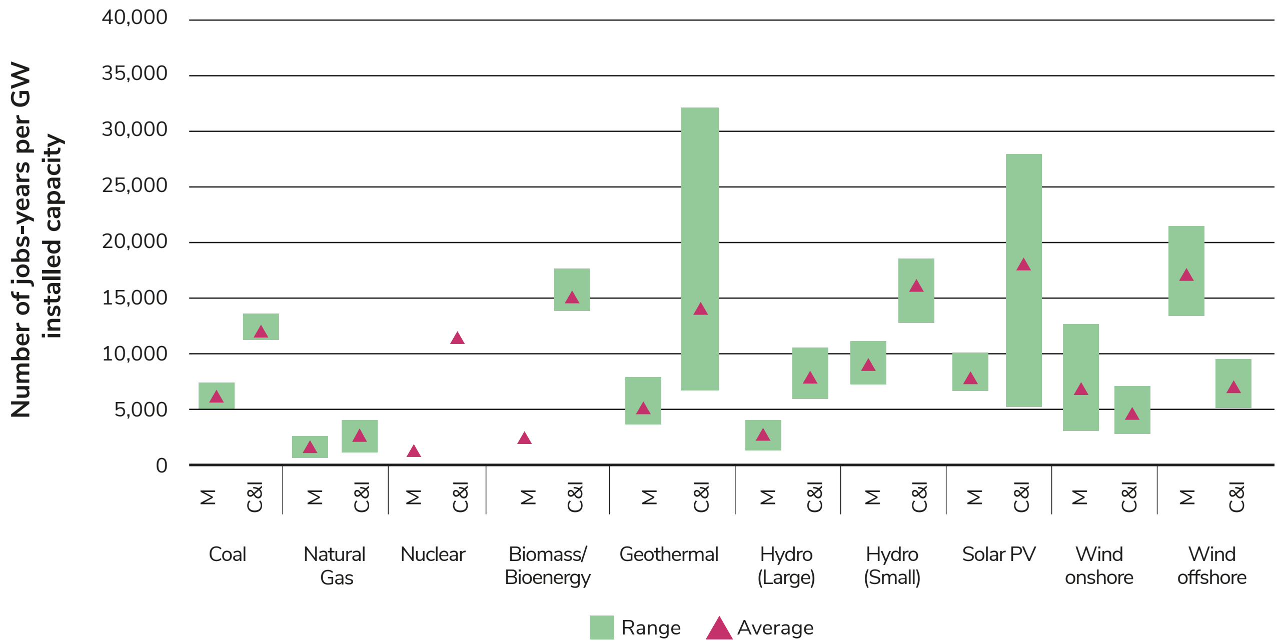
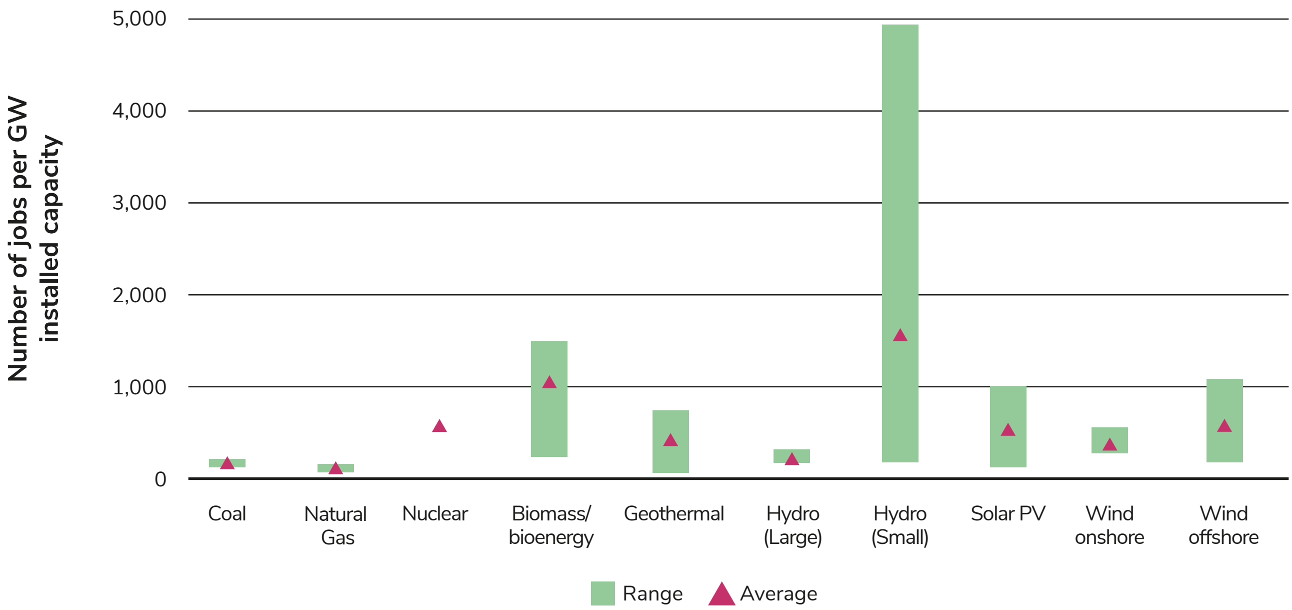


Figure 1b. Gross jobs created in operation and maintenance per GW of installed capacity



Notes to Figures 1a & b

1. Data reflects average and minimum / maximum values extracted from a range of studies (Ortega et al., 2015, 2020; Atilgan and Azapagic, 2016; Henriques, Coelho and Cassidy, 2016; Jacobson et al., 2017; Dominish et al., 2019; Ram, Aghahosseini and Breyer, 2020; Ram et al., 2022). **2.** The job creation data relates to the global scale, Europe and Turkey. **3.** The estimates vary in terms of whether they include direct, indirect and/or induced jobs.

3.2. Policies and job creation

Various studies attempt to associate green policies, including fiscal stimuli, financial incentives and regulations, with numbers of jobs created (e.g. Dsouza, 2015; Dvořák et *al.*, 2017; Mundaca and Luth Richter, 2015; Lim, Guzman and Bowen, 2020; Lee, 2017). Dvořák et *al.* (2017) found that job creation in renewable energy in the Czech Republic has depended upon the continuity of financial incentives, and Lee (2017) reported that regulations mandating action on renewable energy resulted in small positive increases in private sector green jobs in US states. Several documents investigate the role of green job creation policies in boosting employment during times of economic recession. A US-focused study suggests that green stimulus programmes supporting wind power and solar PV helped to boost direct and indirect job creation, expand manufacturing capacity and supply chains, and increase revenue from sales of renewable energy technology (Mundaca and Luth Richter, 2015).

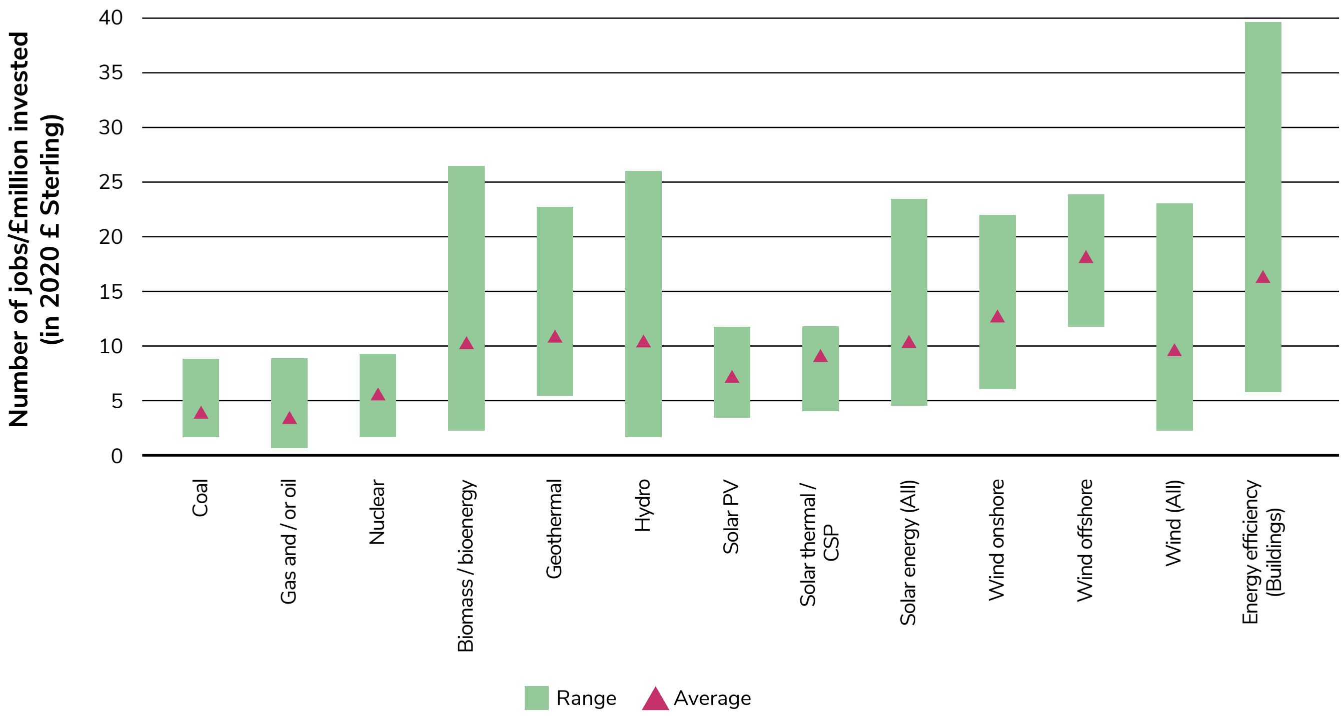
While the circumstances around the COVID-19 economic recession and the 2009 financial crisis are very different, evidence from the 2009 crisis indicates that the green measures (e.g. in renewable energy infrastructure) forming part of the recovery stimulus created more jobs than conventional stimulus measures (Allan et *al.*, 2020).

The CCC recommend that in the short term, *"green stimulus policies can be economically advantageous compared to traditional fiscal stimuli. They tend to have higher short run multipliers and higher numbers of jobs created"* (CCC, 2020, p. 141). Domestic construction projects such as insulation retrofits or building wind turbines may be particularly favourable and less prone to offshoring services overseas. The CCC also suggests (Ibid., p. 141) that in the long term, *"investments in low-carbon and adaptation technologies can lower costs and help to accelerate deployment and innovation in a 'virtuous reinforcing cycle'."* Examples of the latter include rapid falls in cost with increasing scale and deployment of solar PV, wind, and potential battery storage technology.

Figure 2 summarises the evidence identified across 15 studies which estimate the number of gross jobs created per £million invested for different energy technologies. This suggests that renewables or energy efficiency can generate more jobs per £ invested than fossil fuel generation or nuclear power. Fossil fuel generation creates three jobs on average per £million invested, compared to five jobs / £million for nuclear power and 10 jobs / £million on average for the renewable energy technologies shown in the chart. Energy efficiency demonstrates the highest job multiplier per investment, creating 16 jobs / £million on average.

Figure 2 includes energy efficiency as well as renewable energy technologies. Several reports have been published recently, for example by the Energy Efficiency Infrastructure Group (EEIG, 2020) and the Institute for Public Policy Research (Jung and Murphy, 2020; Webb, Emden and Murphy, 2020), which make a strong case for the co-benefits of investing in home energy refurbishments. The UK has one of the oldest, most poorly insulated and draughty housing stocks in Europe (ACE, 2015). Space and water heating in buildings contributes around 40% of UK energy consumption and 20% of UK greenhouse gas emissions (CCC, 2016). Properly insulating UK homes and replacing fossil fuel boilers with heat pumps can help to alleviate fuel poverty, meet the UK's longer-term net zero climate target, and support a just transition: creating jobs in a distributed way around the country, including 'levelling up' in regions most affected by unemployment and lack of investment (EEIG, 2020; Jung and Murphy, 2020; Webb, Emden and Murphy, 2020). Low carbon energy technologies may vary in the extent to which they offer social and economic co-benefits similar to those arising from retrofitting buildings (Gross, 2020a). The spatial distribution of job creation is addressed in the next section.

Figure 2. Gross jobs created per £million invested (jobs/£million)



Notes to Figures 2

1. This chart shows identified evidence from 15 studies on number of gross jobs created per £ million invested for different energy technologies or interventions.
2. The 15 studies were published from 2009 to 2020, pertaining to the US, UK, Europe and India (Pollin and Garrett-Peltier, 2009; Lambert and Silva, 2012; Zabin and Scott, 2013; Markaki et al., 2013; Pollin et al., 2014; Rosenow, Platt and Demurtas, 2014; Calzadilla et al., 2014; Mirasgedis et al., 2014; Bell, Barrett and McNerney, 2015; Cambridge Econometrics, 2015; Mundaca and Luth Richter, 2015; Reddy, 2016; Mikulić, Bakarić and Slijepčević, 2016; Garrett-Peltier, 2017; Brown, Soni and Li, 2020). **3.** The estimates vary in terms of whether they include direct, indirect and/or induced jobs. **4.** Equivalent data for a study on China was also obtained (Chen, 2019), but contained significantly higher job creation values than the other countries / regions (likely due to higher labour intensities in China), and has therefore been excluded so as not to skew the comparison between technologies. **5.** The investment currency in the original datasets has been converted from US dollars or EUR to pound sterling, based on OECD (2021), and then adjusted for inflation to 2020 pound sterling.

3.3. Regional and local job creation

A central theme, connected to just transitions and identified in some of the literature reviewed, relates to the geographic distribution of green jobs. Our review identified limited examples of studies which attempt to quantify the regional distribution of low carbon energy employment. Several recent UK- or England-focused publications identified in our review and included in Table 1 present estimates of how many low carbon jobs could be created in different regions, with potential to help 'level up' employment opportunities between regions. According to ONS (2021a) business survey estimates, there were just over 200,000 direct jobs in the 'low carbon and renewable energy economy' in 2019. However, although this annual dataset shows the level of employment for Scotland, Wales and Northern Ireland, equivalent data has yet to be made available for English regions. An analysis by Ecuity Consulting (2020) applies a similar definition of the low carbon and renewable energy economy to estimate that almost 1.2 million jobs may need to be created in England to support a net zero transition by 2050. The highest regional contributions to job creation are indicated to be in the North West, Yorkshire and the Humber, and the South East (Table 1). A separate evaluation of regional jobs at risk from a shift away from natural gas to low carbon heating indicates that the highest quantity of jobs at risk are in North West England (Webb, Emden and Murphy, 2020).

One interesting feature of regional low carbon job creation is the match or mismatch with existing regional specialisms. For example, there is a broad split in England in terms of manufacturing (concentrated in the North and the Midlands) and services (concentrated in London and the South East). The north of England also has strong expertise in offshore wind and nuclear generation and energy storage (Ecuity Consulting, 2020). It therefore makes sense that where possible, job creation is targeted to sufficiently take advantage of particular regional and local expertise and specialisms. National Grid (2020) estimate the size of a 'net zero workforce' required to transition to a low carbon energy network by 2050, including direct and indirect jobs. The report highlights a "*significant employment opportunity" in the north of England*[2] where their analysis projects that '*nearly 100,000 jobs will become available, the Midlands (over 50,000 jobs) and the devolved nations of Scotland, Wales and Northern Ireland (nearly 90,000 jobs)*' (National Grid, 2020, p. 5). Initial uptake of hydrogen boilers for heating in buildings could be prioritised in close proximity to industrial clusters (with low carbon hydrogen production) in the north of England. Conversely, job creation arising from other interventions such as energy efficiency retrofitting or heat pump installation is likely to be more evenly distributed across the UK (Ecuity Consulting, 2020).

2 The North of England comprises the North West, North East, and Yorkshire and the Humber regions of England.

3

Beyond the UK, it has been suggested that green job creation is more likely in areas of higher per capita income and where employment in high-tech manufacturing and knowledge intensive services is concentrated (Vona, Marin and Consoli, 2018). The regional distribution of new green employment can also assist in substituting displaced jobs. Pegels and Lütkenhorst (2014, p.529) found that renewables component manufacturing in Germany was "*often located in the traditional industrial centres*", some with the "*highest unemployment ratios nationwide*". With reference to South Korea, Park and Lee (2017) state that "*Green industries tend to locate in areas where conventional manufacturing industries were previously concentrated*" which "*suggests potential strategies for local economic development with green industry sectors in traditional manufacturing cities that have experienced economic decline*".

According to a US study, woody biomass power plants using locally sourced feedstocks can generate more jobs locally than coal or natural gas power systems (Dahal et al., 2020). Vona, Marin and Consoli (2018) present evidence, also from the US, that each additional local green job can create between two and four local jobs in non-green sectors. Overall, there appears to be limited evidence in the literature reviewed on the geographic implications of low carbon energy job creation, and more research is required to improve understanding of issues around local or regional displacement and substitution of employment in high carbon sectors.

Table 1. Geographical distribution of low carbon and renewable energy jobs in the UK and estimates of jobs needed for, or at risk from, a net zero transition

Geography	Low-carbon and renewable energy economy, direct jobs, 20191	Low-carbon and renewable energy direct jobs supporting net zero in 20502	Energy generation and network jobs needed to get to net zero by 20503	Annual jobs needed to improve all homes to EPC C rating by 20304	Jobs at risk from a transition away from gas heating5
North East	N/A	84,200	21,500	6,600	0 – 4,000
North West	N/A	170,600	60,500	17,800	More than 10,000
Yorkshire and the Humber	N/A	167,700	17,200	13,700	0 – 4,000
East Midlands	N/A	96,800	18,600	11,300	4,000 – 10,000
West Midlands	N/A	97,000	35,100	14,200	4,000 – 10,000
East of England	N/A	119,300	27,900	14,100	0 – 4,000
London	N/A	143,800	34,200	17,100	0 – 4,000
South East	N/A	163,000	54,900	20,500	4,000 – 10,000
South West	N/A	139,800	43,900	13,300	0 – 4,000
England	165,600	1,182,200	313,800	128,600	N/A
Scotland	21,400	N/A	48,700	11,400	N/A
Wales	9,700	N/A	25,100	7,900	N/A
Northern Ireland	5,300	N/A	13,700	3,100	N/A
United Kingdom	202,100	N/A	401,300	151,000	N/A

Notes to Table 1

1. Low Carbon and Renewable Energy Economy (LCREE) business survey estimates: total direct employment in 2019 (full time equivalent, rounded to nearest 100), including: renewable electricity generation; nuclear power; bioenergy and energy from waste; low-carbon heat; energy efficiency; low-carbon services; and low emission vehicles and infrastructure (Office for National Statistics, 2021a). **2.** Direct low-carbon jobs needed to support a net zero transition in 2050, including: low-carbon electricity; low-carbon heat; alternative fuels; energy efficiency; low-carbon services; and low-emission vehicles and infrastructure (Ecuity Consulting, 2020). **3.** Direct and indirect jobs (rounded to nearest 100) "needed to operate, manage and maintain the network of increasingly clean energy generation, transmission and distribution" and "transform the UK's energy system by upgrading existing infrastructure and building new infrastructure" in order to meet net zero by 2050 (National Grid, 2020, p. 11). **4.** Annual full-time equivalent jobs needed to improve all homes to Energy Performance Certificate (EPC) C rating by 2030 (EEIG, 2020). **5.** Jobs in natural gas production for heating at risk from a move away from gas heating (Webb, Emden and Murphy, 2020).

3.4 Economic impacts of job creation in low carbon and efficient energy

Whilst the evidence reviewed indicates that renewables and energy efficiency can generate more jobs than fossil fuels for the same level of investment, this does not automatically mean that preferential investment in these technologies will lead to higher employment in the whole economy in the long-term. In a depressed economy in which aggregate demand is low compared to potential supply of goods and services (creating a so-called 'Keynesian output gap'), then stimulating additional employment in particular sectors is very likely to lead to higher overall employment, and it makes sense to focus such efforts on more labour-intensive options (Blyth et *al.*, 2014). This is clearly relevant to the UK economy which has experienced a higher rate of unemployment of above 5% during the Covid-19 pandemic in 2020, although this rate has fallen more recently (Office for National Statistics, 2022).

There is a debate in the literature identified in our review around the extent to which policies supporting renewable energy may contribute to longer term economic growth, notwithstanding short-term employment and growth benefits (e.g. Jaraite, Karimu and Kazukauskas, 2017; Safwat Kabel and Bassim, 2019). Policies have economic and societal impacts beyond their initial stimulus impacts. This is particularly true for decisions that 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 enable 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 and of itself economically advantageous. If it implies lower levels of labour productivity (economic output per worker), then it could adversely affect prospects for long-term economic growth.

While well established, high carbon technologies and sectors may be close to their limits in terms of additional innovation and economic productivity gains, investment in less mature, faster growing low-carbon technologies such as renewables could contribute more to productivity through greater scope for innovation and learning by doing (CCC, 2019). Therefore, the employment characteristics that matter in the long run are not jobs per unit of investment, but whether the investment contributes to an economically efficient transition towards the country's strategic goals, taking account of environmental impacts and energy security considerations (Blyth et *al.*, 2014). Since the UK has far reaching ambitions to create a net zero carbon economy it makes sense to look beyond short-term job creation to consider, and if necessary prioritise, the options that can provide affordable and resilient energy services.

4. Findings on job quality and skills

A review of green jobs literature presented by Mattos (2018) suggests that "*evidence on green policy impacts on job quality is minimal.*" In our review of international literature, we have identified a subset of studies which discuss the quality of green or low carbon energy jobs in qualitative terms. We found a limited number of studies which use quantitative metrics to assess employment quality or relative skill levels of low carbon energy compared to high carbon energy sectors. In this section, we discuss key highlights from relevant literature related to these topics.

4.1. Quality of green jobs

Several studies highlight the importance of ensuring the quality of green jobs, and some documents refer to the concept of 'decent work'. For example, Mattos (2018) writes that "*green jobs are, by definition, decent jobs, i.e. a subset of jobs in environmental sectors which provide adequate wages, safe working conditions, safeguard workers' rights and social dialogue, and which provide social protection.*" In other documents identified in our review, higher job quality is described for example in terms of high wages and full-time employment (Jung, 2015), and permanent rather than temporary jobs (MacCallum, 2016; Mattos, 2018).

However, green or low carbon energy jobs may not always or necessarily be 'higher' quality jobs. It has been suggested that direct employment in renewable energy construction or installation may be linked to temporary work which expires on completion of specific projects or might no longer be needed once renewable energy capacity targets have been met (MacCallum, 2016; Sofroniou and Anderson, 2021).

Similarly, the UK's smart meter installation programme will create the need for smart meter installers as a new occupation – but the longer-term job security or career prospects of these jobs require further exploration (Sofroniou and Anderson, 2021).

With reference to data on Scotland, Connolly, Allan and McIntyre (2016) suggest that labour intensity may fall as renewables mature and employment needs shift from construction to maintenance and servicing.

The authors observed that "*between 2007 and 2012 the number of LCEGS [Low Carbon Environmental Goods and Services] jobs declined whereas the installed capacity of renewable generation in Scotland more than doubled*" (Connolly, Allan and McIntyre, 2016). Nevertheless, it is likely that the UK's net zero target will require a prolonged period of construction and installation of new renewables capacity over the next several decades.

4.2. Demographics of green workers and trainees

The representation of women in more technical occupations in the energy sector may reflect low rates of representation in the wider engineering workforce. In the UK for example, only 14.5% of this workforce are women (National Grid, 2020; The Women's Engineering Society, 2022). Several studies were identified which make observations about the demographic profile of employees in relation to green jobs in general, beyond renewables and energy efficiency specifically. Kapetaniou and McIvor (2020) for example distinguish between 'green' occupational sectors which have lower carbon emissions and engage in more environmental activities, and non-green or 'brown' occupations, which are associated with higher emissions and less environmental activities. These authors analysed green and brown sectors in the UK and found that most employees in brown sectors were male and were also more likely to be younger workers (up to 39 years old) compared to green sectors. This study suggests that "*many younger workers still see brown jobs as viable and in some cases necessary career paths*" (Kapetaniou and McIvor, 2020). Sofroniou and Anderson (2021) report that new and emerging green occupations in Scotland are mainly engineering and IT-related jobs, occupations in which women are significantly under-represented. A survey carried out in the Thrace region in Turkey highlighted that only 15% of green job workers who participated were women (Basol, 2016). There is some evidence indicating that education and training for green jobs also tends to be male-dominated (Sofroniou and Anderson, 2021; Mundaca and Luth Richter, 2015), and there is a need to address this gender imbalance.

Mundaca and Luth Richter (2015) observed low levels of women participating in green job training programmes in the US, noting that: "*one potential barrier may have been the nature of training programs themselves, which emphasized on-the-job training that required cooperation with male co-workers and supervisors, unlike the standards-based approach of college degree programs*".

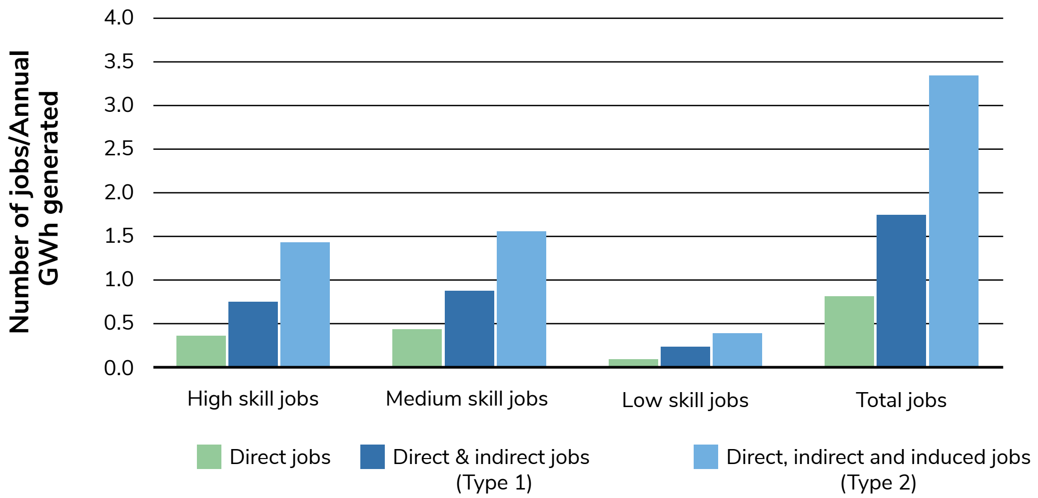
4.3. Skills for green occupations

A cluster of studies was identified around the issue of skills and typical education levels associated with green jobs. Based on an analysis of US employment and occupational data, Consoli et al. (2016) suggest that "*Green jobs exhibit higher levels of education, work experience and job training*" and "*use more intensively high-level cognitive and interpersonal skills compared to non-green jobs*". *This is supported by the findings of a* study (Elliott and Lindley, 2017) that analysed data from the US Bureau of Labour Statistics, and found that green industries "*increased the quantity of workers demanded from the middle of the skill distribution at the same time as they reduced the quantity demanded for lower skilled workers*". The same study went on to conclude that it was "*College graduates who gain the most from the expansion of green jobs*". A German study (Pegels and Lütkenhorst, 2014) used data from the Federal Ministry for the Environment to assess the costs and benefits of Germany's Energiewende, focussing on wind and solar PV. The study found that "*the share of university-degree staff is around three times as high as the national industry average*".

Allan et.*al.* (2021) classify jobs in the UK offshore wind sector according to skill level, through a method involving extraction of data from a UK input-output (IO) table. The data is from 2010, the latest available to allow a detailed breakdown by occupational skills. The authors aggregate nine occupational SIC (Standard Industrial Classification of economic activities) categories to form three groups representing high, medium and low skill levels.

Figure 3 indicates that almost 90% of offshore wind jobs in 2010 were in the high to medium skill categories, and that most jobs are created indirectly in the supply chain or through the induced effect of additional household expenditure.

Figure 3. Offshore wind in the UK: Gross jobs per GWh by skill level, direct, indirect, and induced jobs



Notes to Figure 3

1. Data derived from Allan et al. (2021). **2.** High skill jobs - Managers, directors and senior officials; professional; associate professional and technical occupations. **3.** Medium skill jobs - Administrative and secretarial; skilled trades occupations; caring, leisure and other services. **4.** Low skill jobs - Sales and customer services; process, plant and machine operatives; elementary occupations. **5.** 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', while induced job multipliers (including direct, indirect, and induced jobs) are referred to as 'type 2'.

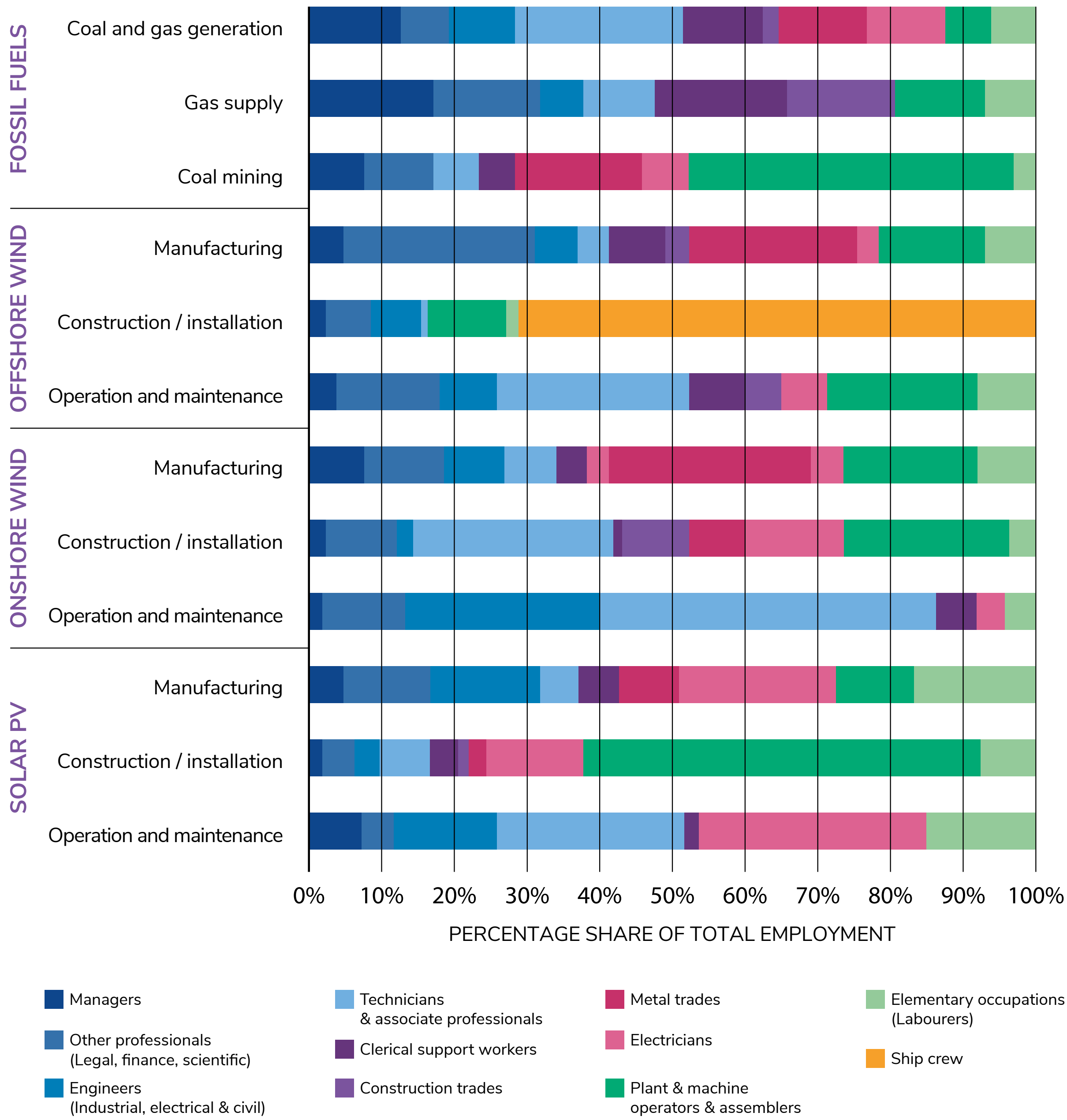
Vona, Marin and Consoli (2018) also report high skill levels and salaries for green occupations compared to non-green employment in the US. Despite some identified differences in skill levels between green and non-green jobs, Reddy (2016) suggests that the skills required are not new, and Bowen, Kuralbayeva and Tipoe (2018) propose that much retraining in the green economy can occur 'on the job'. Others contend that the greening of the economy will require new skills, competencies and qualifications, linked to the creation of new markets and activities (Aceleanu, Serban and Burghelea, 2015; Shanghi and Sharma, 2014). Several studies note the potential to train and employ young people in these new areas, while helping to address youth unemployment (Aceleanu, Serban and Burghelea, 2015; Rutkowska-Podołowska, Sulich and Szczygieł, 2016; Sulich, Rutkowska and Popławski, 2020). Kapetaniou and McIvor (2020) highlight that in the UK, younger and male workers are concentrated in brown sectors, where most jobs require low- or medium-level skills. This implies challenges for younger males working in routine or manual brown occupations if they need to switch to green jobs; they may have to learn new skills in order to avoid job displacement difficulties (Kapetaniou and McIvor, 2020).

The identified evidence does not support a straightforward claim that renewable energy or energy efficiency jobs are more skilled than higher carbon energy sectors, and this depends on the extent to which direct, indirect and induced job creation are considered. Several analyses (e.g. Allan and Ross, 2019; Dominish *et.al.*, 2019) observe that significant shares of employment in fossil fuel generation and extraction are in higher occupational categories. There is also demand for lower-skilled, manual occupations which may for example comprise much of solar PV installation and offshore wind construction activities.

Figure 4 presents a chart of data sourced from Dominish *et.al.* (2019), which compares the share of occupation types and categories for several renewable electricity generation technologies with fossil fuel power generation (and associated activities). The data for solar PV and onshore and offshore wind has been drawn from international surveys carried out by IRENA (2017a, 2017b, 2018). This has then been compared to equivalent occupational data derived from the Australian 2016 national census, which has been scaled using regional employment multipliers to represent different world regions (Dominish *et.al.*, 2019).

The relative distribution of occupations shown in Figure 4 highlights areas where low skilled jobs are particularly concentrated: for example, assemblers comprise the majority of jobs in solar PV installation, and approximately half of all jobs in coal mining are in manual or elementary occupations. Around 70% of offshore wind construction jobs are comprised of ship crew. Plant and machine operators, assemblers and elementary occupations contribute a small but significant share of wind manufacturing and construction activities. Whilst it is clear that higher-skilled professional occupations comprise substantial shares of operation and maintenance jobs in wind and solar PV, Figure 4 does not indicate clear differences between renewables and fossil fuels in terms of relative skill levels.

Figure 4. Share of occupational categories by electricity generation technology / fuel source and activity



Notes to Figure 4

1. Data sourced from Dominish et *al.* (2019). **2.** The occupational data is based on surveys of wind and solar PV industries in various developed and developing countries carried out by the International Renewable Energy Agency (IRENA, 2017a, 2017b, 2018). **3.** Occupational data for fossil fuels has been derived from labour statistics in the Australian 2016 national census, and adjusted using regional job multipliers to account for different labour intensities in different parts of the world (Dominish et *al.*, 2019).

The evidence reviewed suggests that green skills supply and demand should be carefully managed through policies supporting green job creation, and coordination of training activities. According to OECD/Cedefop (2014, p.12) this "*will prevent the situation of green skills demand being stimulated by government policy, but not being matched by equivalent action to meet this demand, leading to skills bottlenecks and/or programme failure due to unskilled operators.*" In the context of India, Reddy (2016, p.300) suggests a need for "*collaboration between government authorities and business houses to develop industry-endorsed training programs that give graduates nationally recognised technological skills and provides skilled employees with a diploma certificate. Secondly, there is need to create a nationwide, online skill database that would link students, colleges and employers.*"

5. Conclusions and issues for policy

In this report we present findings from our systematic review of literature on low carbon job creation, quality, and skills. The international literature revealed various methods and units used to estimate the quantity of low carbon energy job creation. In general, much greater standardisation of methods would be desirable in order to compare how many jobs can be created by low carbon energy and energy efficiency policies both at a project scale and wider societal level. Our findings also underline a relative lack of metrics and data measuring quality, skill, and geographic distribution aspects of low carbon energy job creation, and these should be priority areas for further research.

We compare a range of recent gross job creation estimates which indicate that overall, investment in renewable energy and energy efficiency can deliver more jobs than gas or coal power generation. This finding is consistently supported across a range of different job creation metrics and when focusing on different technology life stages, i.e. manufacturing, construction and installation, operation and maintenance. This suggests that policies supporting renewables and energy efficiency may lead to net job creation compared to the counterfactual of jobs which may otherwise have been created by investing in fossil fuels. A key limitation is that our review did not identify sufficient recent analyses to support a direct comparison of the net employment effects of investing in different low carbon energy technologies or energy efficiency.

Policies supporting manufacturing and installation of renewable energy may be particularly effective at creating short-term jobs and economic stimulus. In comparison, longer lasting operation and maintenance jobs are created over energy technology lifetimes. Evidence relating to the 2009 financial crisis indicates that green measures (e.g. in renewable energy), which formed part of the recovery stimulus, created more jobs than conventional stimulus measures. In the current context of supporting economic recovery from COVID-19, domestic construction projects such as insulation retrofits or building wind turbines could be particularly favourable and less prone to offshoring services overseas.

There is a debate in the literature around the extent to which policies supporting renewable energy may contribute to longer-term economic growth, notwithstanding short-term employment and growth benefits. Jobs created per unit of investment represent only one aspect of a low carbon transition; what matters in the longer-term is whether the investment contributes to an economically efficient transition towards a country's strategic goals, considering environmental impacts and energy security. Meeting the UK's net zero target implies a continuous need for jobs over several decades, e.g. to build the new renewables capacity needed for likely greater demands for electrification from transport and heating, and to carry out widespread energy efficiency and low carbon heating refurbishments across the building stock. Wider impacts of such activities go well beyond job creation to include co-benefits such as improved air quality, more comfortable homes, more resilient energy supplies and reduced dependence on natural gas.

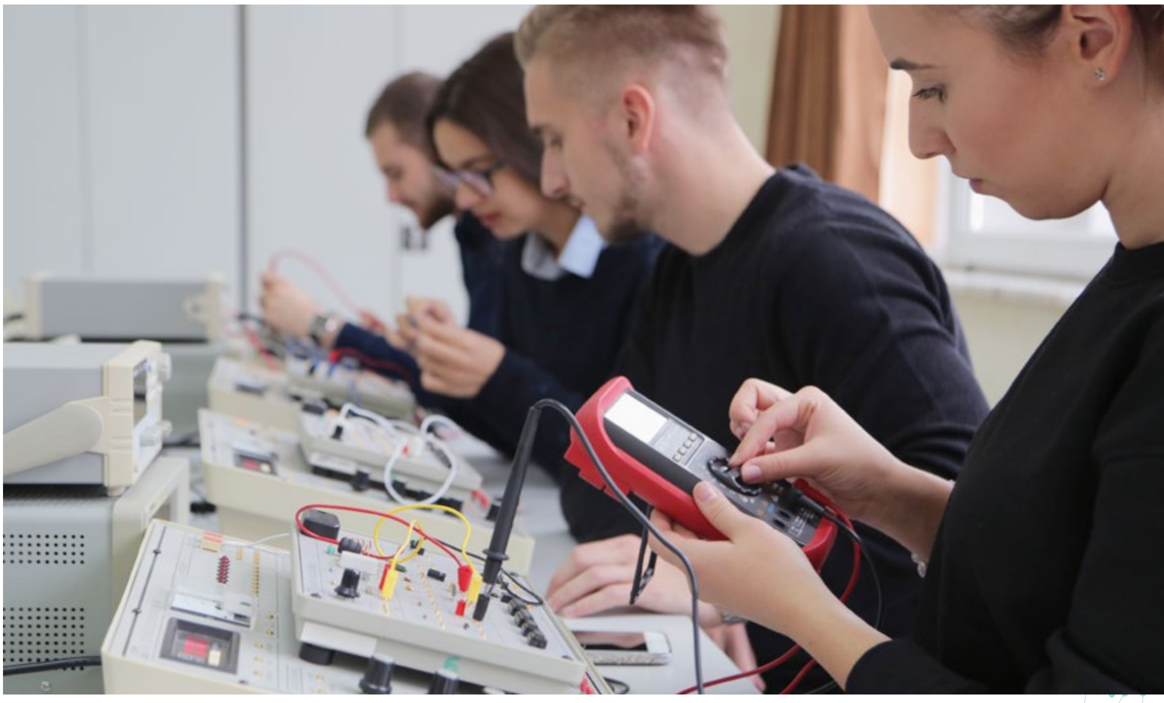
We identify limited evidence in the literature on the geographic distribution of low carbon energy job creation which may have potential to help 'level up' between different regions in the UK. Demand for renewable energy construction/installation and operation/servicing jobs is generally created locally, whereas the creation of manufacturing jobs depends upon the local or national presence of a manufacturing base in renewables or policies to develop such a capacity. We note the potential for green jobs to be located in areas where traditional industry may be in decline.

Several studies quantify significant low carbon employment opportunities in different English regions and devolved administrations, pertaining to energy infrastructure upgrades, energy efficiency and heat decarbonisation. Where possible, job creation in specific low carbon energy sectors could be targeted to take advantage of particular regional and local expertise and specialisms (for example hydrogen production and applications located close to industrial clusters). Building interventions such as heat pumps and energy efficiency are likely to create labour activity which is more evenly distributed around the country. This suggests that supporting a comprehensive national building energy efficiency and heat decarbonisation retrofitting programme could be beneficial in terms of creating employment in a distributed way across regions while contributing to reaching net zero.

It is desirable that a low carbon transition should create quality jobs, for example in terms of adequate wages and employee rights, full-time employment, safe working conditions, and permanent rather than temporary jobs. Direct employment in renewable energy manufacturing, construction or installation, or smart meter installation, has been linked to temporary or short-term work in the literature. It has been suggested that such employment is likely to expire on completion of specific projects or may no longer be needed once renewable energy capacity targets have been met. However, the latter point may be less applicable to the UK context where an ongoing programme of large-scale renewables roll-out will be required to meet net zero. Renewables operation and maintenance jobs are typically more permanent, lasting over technology lifetimes. Labour intensity may fall as renewables mature and employment needs shift from construction to maintenance and servicing.

Various analyses in the literature conclude that green jobs in general tend to be more highly skilled compared to non green occupations. However, it would be overly simplistic to suggest that renewable energy or energy efficiency jobs are generally more skilled than higher carbon energy occupations. The majority of jobs in the operation and maintenance of wind power and solar PV are in highly skilled, professional occupations. There is also demand for lower-skilled, manual occupations which for example comprise significant shares of solar PV installation and offshore wind construction activities. There is a need to co-ordinate the development and supply of training so that it takes full account of the wide range of occupational functions required for manufacturing, building and installing, operating and maintaining renewable energy technologies and infrastructure. Sequential planning will be required to train and coordinate local workforces required for renewables expansion, minimising time gaps between projects and the need for construction workers to relocate.

There is some evidence to indicate that women are underrepresented in green jobs occupations relative to men and that there are barriers to participation of women in green jobs training programmes. Therefore, access of underrepresented demographic groups to training and employment opportunities needs to be improved, and such groups should be encouraged proactively to take up careers in low carbon sectors. There is potential to equip young people with new, green competencies through nationally recognised training programmes and online resources connecting them with potential employers, while helping to address youth unemployment. Green skills supply and demand, including access to and provision of training and apprenticeships, will need to be carefully coordinated with policies supporting green job creation.



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Appendix

Expert Group advisers

The expert advisers were asked to comment on the scope of the project and the proposed approach, advise and assist the project team in the selection of relevant evidence sources, and review draft results. The following expert advisers contributed to the project:

Grant Allan (University of Strathclyde)
John Barrett (University of Leeds)
Will Blyth (Oxford Energy Associates and FCDO)
Lucy Geoghegan (Scottish Government)
Mike Hemsley (CCC)
Bianca Letti (CCC)
Paul Mathews (HM Treasury)
Luke Nightingale (BEIS)
Karen Turner (University of Strathclyde)

The Technology and Policy Assessment team

The UKERC Technology and Policy Assessment (TPA) team 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. Subjects are chosen after extensive consultation with energy sector stakeholders.

The TPA has been part of UKERC since the centre was established in 2004 and is now in its fourth phase, which started in 2019. The primary objective of the TPA is to provide a thorough review of the current state of knowledge through systematic reviews of literature, supplemented by primary research and wider stakeholder engagement where required.

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