Zero carbon as economic restructuring: spatial divisions of labour and just transition

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Zero carbon as economic restructuring: spatial divisions of labour and just transition

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ABSTRACT

Strategies to reduce carbon emissions are set to be a powerful force of economic restructuring, creating new economic opportunities, and also disruption and divestment for some firms and sectors. A pressing issue for 'just transitions' is whether low carbon economic restructuring will challenge or reinforce prevailing geographies of spatial inequality and labour market (dis)advantage. In this article we return to the economic restructuring literature of the 1980s and 1990s to provide a theoretical framework for understanding 'spatial divisions' of low carbon work and how they might be shaped to ensure economically just transition. Our approach foregrounds questions of skills, training and pathways to employment across supply chains as key dimensions of just transition, providing a framework for analysis and intervention. The paper, therefore, brings new critical perspectives on low carbon transitions by conceptualising decarbonisation as a form of spatial economic restructuring and its potential implications in reinforcing and/or working against the existing patterns of uneven spatial development.

KEYWORDS

Zero carbon; economic restructuring; employment; policy

Introduction

Actions to reduce or contain carbon emissions to avert climate change are set to be a powerful force of economic restructuring, creating new economic opportunities and also threatening jobs and investment in sectors unable to adjust to fossil fuel divestment (McEvoy *et al*. 2000, OECD 2012a, Newell and Mulvaney 2013). As decarbonisation starts to become reality, a pressing issue is whether low carbon transitions will challenge or reinforce prevailing geographies of spatial inequality and labour market advantage and disadvantage. This has added salience in the context of post-Covid recovery in countries like the UK, with calls from across political and civil society activists to 'build back better', emphasising the opportunity to use government recovery stimulus to catalyse transition to a 'green' economy (IISD 2020).

There is now a range of literature on potential economic and employment impacts of decarbonisation (Global Carbon Network 2009, OECD 2012a, 2012b). Literature has also begun to explore the relationship between decarbonisation, regional development and regional inequality (Gibbs and O'Neill 2014, 2017, Grillitsch and Hansen 2019, De Laurentis 2020, Trippl *et al*. 2020). As yet, however, there has been limited critical examination of decarbonisation as a wider process of spatial economic restructuring and its employment and labour market implications.

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In this article we return to the economic restructuring literature of the 1980s and 1990s to provide a theoretical framework for understanding decarbonisation as spatial economic restructuring and how this restructuring might be shaped to ensure socially just transition in economic development and employment. A key aim of the paper is to think systematically about spatial and territorial implications of decarbonisation as processes of low carbon economic restructuring (LCER) that destabilises some aspects of economic activity and industry sectors, and also creates opportunities for new business development and job creation. Some of those changes will have particular territorial ramifications (for example, increased investment in offshore wind farms, the decline in oil refineries), which might or might not align with the existing economic geographies, but in other cases geographical patterning will reflect the locational choices of firms. Crucially, in all cases we argue that implications for people and places will be shaped in significant ways by choices about government investment in labour market and training policy, low carbon regulation and infrastructure investment.

A key contribution of the paper is to examine a three-fold process through which (1) economic restructuring impacts spatially in uneven and nuanced ways, and also produces (2) an uneven spatial distribution in the quality of employment (in terms of pay and conditions and in-work training), and (3) public policy mediates (1) and (2), including possibilities to help support people and places facing labour market disadvantage through a range of interventions. As such the paper focuses centrally on the distribution of employment, taking forward insights initially developed in the concept of spatial divisions of labour, which showed how the skewed spatial distribution of lower skilled and professional labour was further reinforced by the tendency for higher value work in manufacturing sectors to be located away from sites of production in more affluent service sector locations (Massey 1984).

We start from the principle that a socially and economically just transitions policy should focus on spatial distribution of quality and quantity of employment for different places, communities and individuals. As Massey (1984) argues, there are powerful factors that reinforce uneven spatial development over time through spatial divisions of labour. In particular, economic restructuring since the 1970s has largely accelerated and reinforced regional inequalities, in part; this is because the decline of manufacturing employment and increased service sector employment has benefitted more affluent regions, but there is a longer history of better paid and higher skilled work in supply chains being located in more affluent regions as successive rounds of investment reinforce the position of places within the wider spatial division of labour (Massey 1984). However, that process always reflects the interaction between new spatial structures of economic restructuring and the accumulated economic, cultural and infrastructural legacies of the past. These insights have potentially significant implications for research on the impact of low carbon restructuring and policy choices for governments.

The paper starts by setting a framework for understanding economic activity in relation to spatial divisions of labour and the opportunities and challenges of economic restructuring. We then explore implications of seeing decarbonisation as a process of economic restructuring. This is explored further by highlighting exemplar dimensions of that restructuring process and what they might mean for regional inequalities and spatial divisions of labour. A key theme emerging from the paper is the importance of state intervention (and investment) in mediating economic development and employment impacts of decarbonisation and this is explored further in the conclusions.

Methods

The argument and analysis of this paper draws on our involvement in a range of research projects on economic development and decarbonisation over the last two decades and desk-based reviews of literature and evidence. Our focus is specifically on 'low carbon' or rather 'low carbon goods and services' as defined – for instance – in the UK government's economic statistics (ONS 2020). A similar analysis could be applied to wider spheres of environment and 'green' employment, or indeed

employment associated with increased climate adaptation (e.g. flood control, green infrastructure). That wider focus is important because low carbon is part of a wider green restructuring that has potentially significant employment impacts, but we have focused solely on low carbon mitigation to keep the paper manageable. It is possible that a low carbon transition might see emphasis on reducing consumption and possibly some form of de-growth (Schlulz and Bailey 2014). It is also possible that low carbon transitions (de-growth or otherwise) might support broader changes in the future and value of different types of work, especially in the context of automation (Bastani 2019). A de-growth perspective is compatible with our analysis because we do not presuppose any level of growth and our interest is in the geographical impacts of low carbon as a process of economic restructuring. It might be argued that without some countervailing governmental strategy, the net impact of de-growth will likely be to benefit more affluent areas that are less vulnerable to economic decline. De-growth as a political strategy will need to be mindful of its differentiated socio-economic impacts and its socio-ecological benefits.

Economic restructuring, the state and spatial divisions of labour

Many factors shape the location of different economic activities in space and over time, including proximity to natural resources, connectivity to markets or other producers, historical sunk costs of investment in infrastructure and machinery, embedded skills and knowledge in economic clusters and local labour markets, the costs and availability of land and labour relative to potential competing places, and so on (Hudson 1988). Embedded within these factors are varying local, national and international regulatory and fiscal policies which affect potential competitiveness of firms. As Poon (2012, no page) argues, 'explaining economic activities in time and space assumes a multi-scalar perspective because economic space is found to be constituted at various scales from the local and regional to the global or some combination of these'. As such, economic activity is about global production networks and an international spatial distribution of labour (see Coe and Yeung 2019).

Our interest in this paper is on the reshaping of economic geographies through economic restructuring that disrupts and alters spatial distributions of economic activity and employment, creating different challenges and opportunities for different places. To varying extents, economic activity and employment is constantly being 'restructured' as firms expand, diversify and decline, jobs are created and jobs are lost. However, prevailing 'structured coherences' (Harvey 1985) and spatial structures (Massey 1984) of economic activity will tend to remain more or less fixed unless there are significant changes in production, transport or communications technology, new consumption norms, changes in state strategy, political disruption or competition from other countries or regions (Pinch 2001).

Economic restructuring is often associated with industrial decline, and specifically the decimation of traditional manufacturing centres in Europe and North America in the 1970s and 1980s as manufacturing moved internationally to regions with lower production costs. However, there are always places and interests that benefit from economic restructuring too (Pinch 2001). Indeed, economic decline of traditional industrial regions in the Global North in the 1980s was paralleled by the growth of higher value manufacturing and services, primarily outside industrial heartlands, as well as vast expansions of economic activity in East Asian countries as part of a new International Spatial Division of Labour.

As Doreen Massey (1984) highlights, there is a tendency for regional specialisms and spatial divisions of labour to persist over time because of the layering of rounds of economic activity and socio-spatial relations (see also Dunford 2003). Research has revealed the nuanced and variable ways economic restructuring impacted different places in the 1980s and 1990s depending on their mix of comparative and competitive advantages (including for some the availability of relatively cheap land and labour) (Jonas 1988, Massey 1991, Jones and Woods 2013). Processes of economic restructuring, therefore, need to be understood as sectorally and geographically specific (Peck 2018): for instance, some jobs and sectors are more footloose than others. It is important here – and for our

analysis below – to note that firm mobility is often mediated by material conditions. The location of natural resources, the existing infrastructure and environmental topographies can be important factors in industrial location and restructuring outcomes (Hudson 1988). Although the spatial outcomes of restructuring are not structurally determined, the character of each region and locality can help shape its spatial impacts (Massey 1984).

Crucially, the social and spatial impact of economic restructuring is mediated by public policy in various ways in the short-term and long-term. Analyses of UK manufacturing decline pointed to policy failings over decades, but limited central government support in the 1980s, and in some respects its deliberate dismantling for ideological reasons in favour of service sector growth, was an important cause for the acceleration of this decline (Judge and Dickson 1987)

In this regard Mackinnon *et al.* (2019) review ideas around the notion of 'path creation', which focuses on 'emergence and growth of new industries and economic activities in regions' (Mackinnon *et al.* 2019, p. 114). A central concern is the ability of actors in places to work with and shape industrial decision-making within and across production networks to cultivate conditions for investment in new industries to create jobs and economic growth. Land use planning and infrastructure investment policies might shape locational patterning of economic activity; government financial incentives and investment might be used to shape locational choices of firms, to attract and hold down investment in the face of international competition or to address regional inequalities and labour market disadvantage. Government investment in skills and employment support can affect the ability of workers to access jobs and locational choices of different firms. The spatial distribution of economic activity might also be influenced by innovation policies and infrastructure investments or by environmental and labour control regimes. As we explore below, innovation and job creation in the low carbon economy can be stimulated by environmental regulation, though jobs might also be lost in sectors affected by those regulations.

The potential for state and non-state intervention to shape processes and outcomes of low carbon restructuring is reflected in notions of 'just transition' (Newell and Mulvaney 2013). Emphasis, in that framework, is placed on ensuring that investment in support of economic restructuring is managed in ways that do not reinforce or extend the existing spatial inequalities, and ideally that governments use powers of low carbon regulation and investment to address regional inequalities and labour market disadvantage. This includes action to create opportunities for firms and workers in areas most affected by restructuring and to ensure that decent work is evenly distributed, respecting principles of social and spatial justice. The emphasis on decent jobs is particularly pertinent in the context of increased job precarity in many countries and the rise of zero-hours and outsourced work (Hudson-Sharp and Runge 2017).

Decarbonisation as economic restructuring

Governments around the world are gradually introducing more stringent frameworks for radically reducing carbon emissions by decreasing or phasing out the use of fossil fuels such as oil, gas and coal. This is a process of economic and societal decarbonisation. It is now common to talk about a distinctive low carbon economy, as well as economic impacts of carbon legislation and societal decarbonisation in different sectors and for the overall economy at international, national, regional and local levels. We suggest that there are three main dimensions to economic restructuring through decarbonisation.

First, decarbonisation will lead to decline over time in economic activity related directly to extraction, processing and sale of fossil fuels. Second, as a process of changing and revaluing fossil fuel inputs (While and Eadson 2019, Eadson and While 2019), decarbonisation will also impact the existing forms of economic activity that currently depend on fossil fuels, including plastics, manufacturing, cement, steel and metals processing, aspects of food production that depend on fossil fuel fertilisers, and any industry whose business model is predicated on fossil fuel transportation. Many of these industries will remain essential to a low carbon economy. But whether individual

businesses in those sectors will decline, continue or flourish in a low carbon economy depends on their ability to adapt and remain competitive when alternative energy and transport sources or raw materials are used (Fankhauser 2013). This includes new spatial economic competition based on reduced transport costs or access to reasonably priced renewable energy, green fuel and other low carbon technology (Jonas *et al*. 2011, Hodson and Marvin 2012). Third, new forms of economic activity and job creation will emerge or expand because of low carbon transitions, including production of renewable energy (and its equipment supply chains), low carbon products and materials and business support (Fankhauser and Kotsch 2018). There is considerable work by governments and firms to anticipate future change, and also by governments to set out stable regulatory frameworks, such as zero-carbon emissions targets to guide investment and restructuring decisions.

There are various projections of what LCER might mean for economic activity and employment (OECD 2012, Blyth *et al*. 2014, ILO 2018, Pestel 2019). Yet quantifying future economic and employment impacts of decarbonisation is difficult because much will depend on choices made by governments about how to decarbonise, over what timescales, the balance of legislative and economic instruments and the extent to which there are shared international frameworks. Equally important, decarbonisation is not the only element of on-going economic restructuring and its economic and employment impacts will be shaped by factors such as automation, changes in climate and weather and responses to economic shocks such as the 2020–21 coronavirus pandemic. The economic impact of decarbonisation will vary geographically depending on the mix of international, national and sub-national carbon regulation, the differential exposure to that regulation and differential opportunities and capacities to benefit, respond and adjust. There will never be a definitive answer as to whether there will be more or less economic activity overall – or more of fewer jobs – because of decarbonisation alone, especially as decarbonisation will always be a work in progress and affected by other aspects of economic restructuring.

What is certain is that in the churn of economic activity and job loss/creation, the gains of the low carbon economy will not be an exact replacement – in terms of skills level, pay and condition, accessibility to those made unemployed, spatially – for what is lost. Some places and some workers will gain and some will lose. For example, older workers in declining energy-intensive industries will likely find it hard to find similar well paid or skilled work in low carbon work (Callan and Bowman 2015). In that respect a key issue will be to think about the differential impact of decarbonisation on particular territories (countries, regions, places) and people within those places. Subsequent sections of this paper examine the nuanced geographies of low carbon restructuring in more detail.

As suggested in the section above, the outcomes of economic restructuring can be shaped in fundamental ways by state strategies. This is especially the case with low carbon restructuring because, in addition to choices about whether and how to support adjustment of key employment sectors and new sectors (through investment in equipment and technology, R&D and innovation policy, tariff protections, start up support and so on) and the reskilling of workers, the pace and direction of low carbon restructuring will also be shaped by choices over legislation and regulation. In short, governments can take a long-term strategic view of decarbonisation pathways that might include decisions about how best to manage the existing and future uneven development and spatial inequalities. Elements of low carbon restructuring (and related emphasis on energy security) could prompt rethinking the economics of outsourcing and build indigenous capacity in energy production and key economic sectors. There is now a well-established literature on the need for just transitions frameworks that reflect potential to address inequality and disadvantage through decarbonisation (Newell and Mulvaney 2013, Stevis and Felli 2015, Healy and Barry 2017).

Economic geographies of decarbonisation: four dimensions

The following sections examine different dimensions of LCER associated with decarbonisation, their potential geographical impacts and the role of the state in mediating these impacts. We highlight four key dimensions of socio-spatial impact:

(1) New resource geographies of decarbonisation – some economic activities will develop around natural resources that become more valuable in a low carbon future.
(2) Holding down energy-intensive industries – energy-intensive industry will still be required in a low carbon future, but it will be more energy efficient and less dependent on fossil fuels. How might geographies of low carbon infrastructure and renewable energy provision shape the economic geography of energy-intensive business?
(3) Attracting and creating low carbon products and services – this dimension examines whether low carbon growth sectors which are, in principle, geographically mobile will reinforce or challenge the existing spatial divisions of labour.
(4) Mitigating eco-precarity – this cross-cutting dimension highlights growing concerns about an eco-precariat, highlighting the importance of understanding emerging spatial divisions of labour and recognising that low carbon jobs are not automatically 'good' jobs.

Table 1. Dimensions of low carbon restructuring, implications for spatial divisions of labour and state mediation.

Dimension of restructuring	Impact on economic activity and employment	Spatial underpinning	Implications for spatial divisions of labour and regional inequalities	Role of the state in mediating SDOL
1. New low carbon resource geographies	Sites of fossil fuel production (extraction and refinery) exposed to disinvestment and jobless but new job growth in installing and running investments in renewable energy production.	Renewable energy generation located close to sources of renewable energy. Significant potential for new job creation in urban areas and also around key servicing sites for large-scale energy generation in certain rural and coastal areas. Potentially significant loss of jobs and economic activity in localities linked to the mining or processing of fossil fuels.	Opportunities to create good (skilled, well paid, longer term) jobs in peripheral areas and also for the disadvantaged in urban areas around sites of renewable energy generation. Could be enhanced if R&D and manufacture is co-located. Decline in sectors affected by the decline of fossil fuels is concentrated in already disadvantaged areas and is not necessarily replaced by renewable energy jobs growth. Dangers that disadvantaged groups might be left with precarious jobs if there is not enough education and training support.	Managing spatial competition between potential sites of low carbon energy generation to maximise or balance economic and social employment benefits. Policies to encourage co-location of R&D and energy generation in peripheral areas. Provision of employment and skills programmes so that local people can access better jobs.
2. Holding down high-emission industries	Will require access to reasonably priced low carbon energy to remain economically competitive.	High emission industries tend to be located in less affluent areas.	High emission industries can provide access to relatively well-paid, skilled jobs in peripheral locations and support innovation local supply chains.	Helping to ensure that low carbon energy infrastructures are in place and sufficient.
3. Low carbon growth sectors	Demand for low carbon products and services.	In principle could be located anywhere.	Tendency for high value economic activity (R&D, green finance) to cluster in already advantaged places. But potential for clusters of low carbon technology in peripheral areas e.g. close to renewable energy generation sites.	Support to develop clusters of new low carbon industries in areas of disadvantage, including skills and employability support and industrial cluster policies.

A summary of key themes and implications for spatial divisions of labour and the role of state mediation are set out in Table 1.

Making the most of new resource geographies

There is a longstanding interest in economic geography on economic activity linked to particular mineral, ecological or geological resources, including access to water, mining, ports and other sources of natural comparative advantage (Bridge 2009). Fossil fuels have distinctive resource geographies relating to geological reserves of oil, coal and gas and also to infrastructures of transportation and processing of those raw materials, their impact on the location of energy-intensive manufacturing, the burning of fossil fuels for energy in power plants and the manufacturing of things that rely on fossil fuels (notably automobile plants) (Bridge 2011). Some of those comparative economic advantages will be undermined by decarbonisation, as fossil fuels lose value and infrastructures of fossil fuel processing become increasingly redundant. Energy-efficient manufacturing will still be required, but its competitiveness and economic geography will be shaped by the access to low carbon energy and the extent that rationales for investment in the existing plant (or the employment and economic benefits) are sufficient to justify extra investment by firms or governments in bespoke low carbon infrastructure. Places with high concentrations of fossil fuel dependence as their economic base – ranging from Gulf states to mining and fuel processing communities – will face pressing challenges of economic and employment decline.

The other side of low carbon resource geographies is the potential for some places to exploit access to revalued geological and biophysical resources for renewable energy generation, biofuels, low carbon materials, and possibly the capture and storage of fossil fuel emissions. There is already considerable interest in the global economic geography of innovations and production in renewable energy technology, including moves to protect national industries through import tariffs (Meckling and Hughes 2018), especially given Chinese dominance of renewable energy technology (Mulvaney 2019). However, there is a distinctive resource geography dimension to renewable energy as jobs are created around harnessing of wind, tidal and solar resources, biomass production or geological resources for carbon capture and storage. All places, and especially cities, have the potential to generate jobs through energy-efficient measures and decentralised energy generation through the installation and maintenance of machinery and equipment (even if jobs are lost as decentralisation replaces power plants in other places). In the Global North and the Global South there is interest in the potential to create meaningful pathways for urban employment in these sectors and to combine employment, climate and social benefits through decentralised renewable energy (OECD 2012a, 2012b)

But levels of sunlight and onshore and offshore wind speeds can vary widely, as can the potential for biomass and biofuel production (Elberson *et al*. 2012, World Bank 2020a, 2020b) and that includes competing land use pressures and land values (Van Der Horst and Evans 2010). Thus some places are becoming new economic centres for large-scale renewable energy generation, such as onshore or offshore wind farms or large solar farms in the deserts of California. The direct employment generation of those facilities varies, but new economic centres act as clusters of economic activity in maintenance and management. For example, in the UK, proximity to powerful wind resources in the North Sea and its well-developed port infrastructure has led to the Humber estuary becoming a focal point for offshore wind industry, including a Siemens wind turbine factory (Jonas *et al*. 2017, Jensen and Gibbs 2018). There are similar stories across the UK and in countries with a coastline where wind power is being developed, as localities with active, redundant or underused ports seek to establish a role as the service points for offshore wind. The UK Humber region is additionally seeking to exploit its geological potential for carbon capture and storage to maintain and extend its clusters of energy-intensive industry (Zero Carbon Humber 2020). Much of the employment generation in low carbon energy is about installation, servicing and maintenance of machinery and equipment that make use of and develop the local skills base (Dawley *et al*. 2019).

The extent that low carbon natural resource advantages are converted into local economic benefit will depend on location, connectivity and broader decisions about low carbon regulation and public and private investment in facilities and infrastructure. Indeed, power stations will continue to be significant employment generators if they switch from fossil fuels to biomass; and sunk costs of power stations mean they will likely be prioritised in low carbon retrofit, sometimes even if retrofit compromises low carbon goals (Cowell 2020). In relation to wind power, in England local institutions do not have control over seabed use, which is the domain of the UK's Crown Estate. As such, onshore servicing development has been contingent on the Crown Estate awarding marine sites to developers (Dawley *et al*. 2019) Furthermore, ports in the UK are privately owned, which led to the competition between port owners across the Humber region. Lengthy planning and legal battles, concerns about the UK's supply chain capabilities and an uncertain policy context for renewable energy in the UK, almost led to the cancellation of the Siemens project on the Humber Estuary before it was finally confirmed in 2014 (Dawley *et al*. 2019, Jensen and Gibbs 2018).

By contrast, in Germany a more interventionist industrial policy combined with stronger local state strategic steering have produced a more variegated geography of turbine manufacture and technology development, while coastal deployment sites have nonetheless become key cluster points for the sector. One example is the city of Bremerhaven where local and regional state institutions were instrumental in developing offshore wind capabilities, including redevelopment of former shipbuilding docks and proactive intervention to ensure colocation of manufacturing and deployment through subsidies, fast-tracked planning consent and actively fostering networks between firms to encourage the collaboration and development of co-benefits (Jonas *et al*. 2017, Mackinnon *et al*. 2019). As well as stimulating local investment and firm creation, these policies encouraged firms operating in the supply chain to relocate to the area from elsewhere in Germany (Dawley *et al*. 2019). In 2014, around 4,000 people were employed in the Bremerhaven offshore wind sector, compared to around 800 in Hull (Jonas *et al*. 2017).

A distinctive element of the development of offshore wind facilities is their re-use of port infrastructures that had previously declined because of changes in shipping practices and fishing industries. At play here perhaps is the 'geological' process whereby infrastructure-intensive low carbon development layers onto previous round of economic development and investment (see Massey 1984). However, an important issue that has been so far under-researched is the quality of jobs created around new resource geographies (including issues of training, career progression and access to work) and the spatial distribution of employment and labour across supply chains of renewable energy generation. It should also be noted that these low carbon resource geographies might result in lower carbon outcomes overall, but their infrastructure and operation is not necessarily clean and green (see for example, Mulvaney 2019). This aspect of 'dirty' green capitalism is often to be found in less desirable places reflecting the previous industrial infrastructure of ports, power plants and nuclear facilities.

Overall, across new economic resource geographies we see some layering of potential opportunities in places with historic infrastructure (e.g. ports for windfarms; existing power stations for biomass) and some new sites of economic potential for deployment of energy production technologies. In both instances the economic potential is not evenly distributed even between places with similar resource potential. We also note that beyond the division of labour that sees manufacturing processes more concentrated in older industrial places, more hazardous extraction processes tend to be found in economically poorer places (typically in the Global South) with fewer worker or environmental protections. What comes through is the critical role of state intervention through regulation and also at local levels as mediators of emergent economic geographies: local state institutions and partners as critical to path creation where the potential for economic development and employment creation can be identified.

Holding down energy-intensive industry

As suggested above, potential natural resource advantages only become economic advantages if they are brought into being through investment choices of governments or the private sector. Decarbonisation creates conditions to revalue not only natural resources but also new investment. As the example of UK wind power demonstrates, this can result in spatial competition to become service sectors of low carbon resource geographies, with clusters of economic activity building competitive advantages.

Public and private infrastructure investment choices are also important as LCER impacts energy-intensive and energy-sensitive industry. These are sectors that are not regulated out by low carbon regulation – though they might be replaced or partially replaced by other materials or new production processes – but they will be sensitive to increased energy and transport costs. Examples include steel production, manufacturing plants, data hubs, cement production, controlled environment agriculture, and distribution centres. Aspects of that production might be phased out or production efficiency improved, but they will remain as significant sources of employment in low carbon transitions. In this respect, low carbon policies and regulation will layer onto other factors influencing competitiveness, which will include variability of carbon regulation between and within countries.

Globally LCER has the potential to alter locational dynamics of aspects of the existing economic activity in two dimensions. First, to the extent that carbon regulation is applied in similar ways to all countries and sectors, the increased costs of carbon 'outsourcing' (i.e. where countries and firms benefit from cheaper manufacturing in countries with less stringent carbon regulation) are likely to alter decisions about where to locate manufacturing facilities. A common framework for low carbon regulation could certainly support the return of manufacturing closer to places of consumption, especially as labour costs increase in countries like China and as new technologies such as automation are used in manufacturing (Ancarani and Di Mauro 2018).

Second, governments will need to ensure that there is an appropriate low carbon energy infrastructure to hold down and attract energy-intensive industry if those sectors are to be economically competitive. Many countries now have decarbonisation plans for high-emitting industries (see for example, BEIS 2017). This can include direct intervention in strategically important industries. In Sweden the government's energy agency has invested over US$50 million to support piloting and demonstration of innovative low carbon steel manufacturing process through HYBRIT, a partnership between Swedish state-owned energy company Vattenfall and iron and steel producers to replace coke traditionally used in steel production with hydrogen (Bairstow 2019). The rationale for the grant was to ensure long-term competitiveness of Swedish steel industry in the context of decarbonisation imperatives (Vogl *et al*. 2018, Hildingsson *et al*. 2019). Because of perceived local economic and employment benefits to places, there was a competition between the existing steel plant locations, with lobbying from local stakeholders and trade unions for investment (Vogl *et al*. 2018).

In most countries, the provision of energy infrastructure for industrial decarbonisation will be determined by a combination of national, regional and local investment and management strategies and initiatives such as Eco-Industrial Parks (EIPs). The principle behind EIPs is that firms can reduce costs and environmental externalities by developing synergies with other firms located within the EIP, for instance, by co-locating firms producing similar types of waste alongside a firm that specialises in using that waste to produce other products (Roberts 2004, Gibbs and Deutz 2007, Guo *et al*. 2017). Examples of this might include using water from industrial cooling processes to provide heating to firms in EIPs, or processing sewage for different industrial and commercial uses (Gibbs and Deutz 2007, Bellantuono *et al*. 2017).

High emitting sectors are not confined to production industries. For example, central to the functioning of contemporary society are data centres, which remotely store, process and distribute data from IT systems. They are also energy intensive, with resulting high GHG emissions: globally it is estimated that data centres account for 1–2 per cent of total electricity usage (Coronan *et al*. 2019).

Places and countries have often incentivised locations of data centres in their territories, with perceived economic benefits following, including good quality jobs in construction and on-going operations of data centres (Grant Thornton 2018). Because of the energy intensity of data centres, as with the examples provided above, national and regional governments have often provided some insulation from rising energy costs and associated 'green' taxes: for instance in 2016, Sweden reduced its electricity tax rate by 96 per cent for data centre developments. Other European countries also have energy tax incentives in place. However, growing concern for the environmental impact of data centres has led to more interest in providing low carbon solutions to reduce energy costs (Coronan *et al*. 2019). These, in turn, have potential impacts for the location of data centres, and as a result location of their economic benefits. In Sweden, tax incentives have been scaled back and cities are looking at alternative measures to support data centres.

In Stockholm, for instance, local government uses data centre waste heat to fuel its district heating systems. This has created an additional incentive for data centres to locate in the area, providing a source of income to offset energy costs (Biba 2017). Other locational advantages include cold climates to reduce costs of cooling (Coronan *et al.* 2019) and some companies have also explored under-sea data centres, which again might confer competitive advantage to coastal cities. Canada, Scandinavia and even Ireland are seen as desirable locations, in part, due to cool climates and in some of these cases access to abundant renewable energy and/or cold-water sources (Vertatique 2017). One high profile example of data centres locating for advantageous environmental conditions is Facebook, which has constructed three data centres in Lulea, Sweden, making use of the cold climate and abundant renewable hyrdoelectric energy to reduce energy costs and carbon emissions. The decision to locate here was, however, influenced by an intensive period of negotiation and lobbying from local government and economic agencies in Lulea, against competition from other sites in Scandinavia (Harding 2015, Vonderau 2019). As with productive industries, it is likely that low carbon infrastructural advantages will grow as a source of competition for data centre location as LCER bites further.

Support for energy-intensive industry will also be important in strategies to benefit from manufacturing value chains for clean technology. As explored above, countries might seek to manufacture wind turbines rather than simply install technology from elsewhere (see Lachapelle *et al*. 2017) and manufacture close to deployment sites can reduce transport costs. One issue for global governance of low carbon spatial divisions of labour could be to manage the changing landscape of competitive advantage in affected sectors so that relocation of economic activity to more affluent nations (which might have more resources to invest in low carbon energy) is balanced with the support for countries where employment and investment might decline. This includes the prospect that lower cost locations will be even more locked into dirtier, more dangerous and lower value aspects of production and manufacturing, whilst more affluent nations continue to benefit from outsourcing those activities.

Again in this dimension of LCER we see how state intervention is important to creating conditions for continued or new economic development in a low carbon transition. But, to some extent new resource geographies are predicated on redeploying existing economic infrastructure allied to resource access, an important aspect for holding down or attracting energy-intensive industry will be the development of new low carbon urban infrastructures, and strategic selective investment in demonstrations projects to reduce costs for high-emission sectors. The role of the entrepreneurial local state (Harvey 1989) is important in attracting and retaining high-emission industry where it is seen as important to local economic development. This implies the potential for reinforcing existing divisions of labour between countries and places with varying capacity and willingness to invest and shape low carbon infrastructure development to maintain comparative advantages.

New low carbon growth sectors

Our third element of the new economic geography of decarbonisation relates to new economic activity in the development, production and management of clean technologies ('cleantech') and low carbon business services. Examples might include wind power technology, biofuel development, nuclear facilities, driverless vehicles, electric vehicles, batteries and so on alongside green finance and other aspects of business support. Economic activity in these sectors can reflect a mix of R&D, manufacture and maintenance/services and that distinction is important for geographical patterning of economic activity.

One question is the extent that these growth/sunrise sectors are layered onto (and might partially replace) the existing centres of manufacturing, research and R&D. It might be expected that the overlap between the existing centres and low carbon growth sectors will be particularly significant for R&D, and green finance would certainly be expected to follow the existing geographies of financial services: for instance, the location of the UK Green Investment Bank in Edinburgh reflects the city's history as a finance hub.

But as Demirel *et al.* (2019) show, relatively little is known about locational choices of green entrepreneurs or the potential for geographic clusters of low carbon goods and services. One example is the potential for green entrepreneurship around key decarbonisation facilities (see Section 'New low carbon growth sectors') or around distinctive university and private sector research centres. Green entrepreneurship might also come out of centres of alternative green economies developed through active state intervention and citizen pressure (Gibbs and O'Neill 2017). Demirel *et al.* (2019, p.763) indicate, 'increasing attention has been devoted to the relationship between environmental innovation, business activity and regional policy'. Gibbs and O'Neill (2017) for example, show how 'the worldwide No. 1 green tech cluster' (Eco World 2015, in Gibbs and O'Neill 2017 p.166) in the Styria region of Austria has developed through a combination of bottom-up support for green economic development and regional policy measures, including strong partnerships between research, industry and policy organisations. In Styria, a history of high-polluting steel and paper manufacturing created pressures for more sustainability focused economic development (van Heyningen and Brent 2012). A central element of this has been a government-supported networking and business support organisation (Eco World Syria), which also seeks to connect Styrian businesses to new markets and technologies, as well as acting as a branding initiative for the region's cleantech activities. Local regulation and support for renewable energy has also created a favourable context for low carbon investment (Gibbs and O'Neill 2017). Bremerhaven (see Section 'Holding down energy-intensive industry') provides another example of long-term state support to develop cleantech clusters, as does the Ruhr Valley in Germany. In the Ruhr Valley, experience of innovation to minimise environmental impacts of coal and steel production to meet regulations meant people and firms in the area were well-placed to develop new environmental technologies and – supported by local and regional state investment, also involving local universities – the Ruhr Valley has become an environmental technology hub, employing around 100,000 people (Galgóczi 2014).

Emergence of cleantech clusters in particular places, 'has not been a matter of chance' (Tveldt 2019, p.54). Clusters, which attempt to break the existing path-dependencies and economic geographies, rely on long-term strategic state support, including employment and skill initiatives. Emergent cleantech clusters have also tended to develop from the existing economic strengths: Tveldt (2019) outlines the importance of the existing strengths in biosciences in San Diego as a starting point for a new cleantech cluster; and the existing ICT prowess in Dublin. In Bremerhaven and the Ruhr clusters have developed around manufacturing and industrial processes, which continue to have strong locational ties (around cheaper labour, physical resources and so on). In each case there is a coupling of R&D investment alongside expertise in the existing industries complementary to cleantech development.

Overall, the path of least resistance is for cleantech clusters to emerge where high-tech R&D is already prevalent. This assertion is reinforced by the geographic analysis of cleantech start-ups by

Marra *et al*. (2017), finding the largest concentrations in already R&D-heavy metropolitan areas such as San Francisco (the largest concentration, accounting for 7 per cent of start-ups identified), London (5.8 per cent), New York (4.7 per cent), Cambridge (4.6 per cent), San Jose (3.3 per cent), Austin (3.1 per cent) and Boston (3.1 per cent). In general, then, although new resource geographies of low carbon create possibilities for changing pathways of economic development in some places, without strategic state support it is likely that the overall pattern of cleantech activity will follow pathways produced in previous rounds of restructuring since the 1960s and 1970s. The relative mobility of these sectors perhaps makes it less likely for them to 'choose' to locate in peripheral places close to heavy manufacturing and with historically lower skill levels. Whereas high emission industry might relocate for lower employment or regulatory costs, higher skilled cleantech jobs are more likely to cling to places where higher skilled labour and associated 'creative milieu' can be found. The examples of Bremerhaven and the Ruhr provide an example where labour processes across production – from R&D through manufacturing – have been brought together locally. But that has required early intervention within industrial lifecycles and long-term strategic investment by local and national state institutions to shift embedded labour geographies.

Employment in the low carbon economy

So far our mapping of different dimensions of decarbonising economic geographies has focused mainly on the location of different types of economic activity. However, as outlined in our theoretical framing, a just transitions perspective is not simply interested in the spatial distribution of economic activity. It asks questions about what that means for spatial distribution of employment overall, emphasising distribution of types of job, including pay, working conditions and training opportunities. This includes the potential to create meaningful new pathways to employment for different disadvantaged groups and meaningful alternative pathways to employment for those whose jobs are lost or downgraded because of decarbonisation or the combination of decarbonisation and other factors (such as automation). There might be the potential for pathways to employment to be created around localised low carbon restructuring initiatives (low carbon infrastructure projects or energy-efficient measures) or new low carbon facilities (for example, increased food growing in cities).

In this context, there is a growing volume of work critically appraising the nature of work generated by green capitalism and the low carbon economy. Neimark *et al*. (2020) talk of a new eco-precariat in which certain subsistence-level economic activities might become outlawed or heavily proscribed through increasingly stringent carbon control, particularly affecting people in the global south. In urban areas across the globe there are long-established informal economic sectors involved in waste collection, reuse and recycling, often offering a precarious source of income for homeless people (Rogerson 2001, Bisschop and Coletto 2017). There is also evidence of an emergent eco-gig or casual economy for certain forms of activity involved in the low carbon transition. Castellini (2019) highlights these trends through the analysis of the Toronto (Canada) 'green' labour market. They draw attention to a green economy which 'not only uncritically accepts precarious labour, but also experiments with innovative ways to justify it' (Castellini 2019, p. 64): for instance, through framing environmental work as morally rewarding or as a 'life's work' to justify low or no pay, flexible working patterns and relatively uninspiring work.

Furthermore, the green economy is framed in job adverts as a new and exciting sector of work, using the language of agility, flexibility and dynamism seen in other, more technologically driven start-up industries to justify the need for workers to 'react positively to flexibility-driven labour regimes' (Castellini 2019, p. 67). This example shows how the development of new economic sectors, as a function of economic restructuring, can provide a point of departure from the existing path dependencies around, for example, employment practices or industrial relations (or at least accelerate emergent trends).

Even within industries that are touted as providing good quality, skilled work, such as offshore wind, there is evidence that jobs can be insecure, involve high prevalence of agency workers and that there are variable levels of unionisation and worker representation in formal decision-making (Schulte 2016). It is useful to look in a little more detail at the offshore wind industry given the vaunted potential for employment generation. Like Schulte (Schulte 2016) Mette *et al*. (2017) also highlight the varying conditions for people working in offshore wind. They outline employee experiences of working offshore in the German wind industry, drawing attention to the physically demanding work involved, including peer-pressure to work in difficult or unsafe weather conditions. Workers' work-long shifts, described as 'lengthy and tedious' (p. 5) and a feeling that workers were constantly working interspersed with days waiting on board ships waiting for the right weather conditions to carry out installations or maintenance.

In a study of offshore wind manufacturing in Denmark, Germany and the UK, Schulte (2016) found that 'in general job quality is low', with a dualised labour market of a large number of sub-contracted temporary agency workers and better paid, more secure employment for fewer workers directly employed by offshore firms. An uncertain market and policy environment in each country had contributed to volatile demand for offshore wind construction, which encouraged the use of temporary over permanent staff, and also meant that 'core' staff positions were also uncertain and the relatively high numbers of agency staff on lower wages also helped to depress wages for 'core' staff. Automation has also led to reduced need for workers in manufacturing and assembly. Since 2017 contractors in the UK have made use of temporary relaxation in immigration rules for the offshore wind sector to bring in migrant workers specifically to work on offshore wind sites, reportedly employed at rates significantly below the minimum wage (The Guardian 2018).

Technologies, central to low carbon transition, such as wind turbines, batteries and solar PV, all still require mineral resources for their construction. As briefly noted in Section 'Holding down energy-intensive industry', the analysis of production networks for some of these products brings to light distanciated chains of exploitation in these green industries. Mulvaney (2019) draws attention to how workers involved in production processes for Solar PV – often in lower-income nations with less stringent employment regulations – can, therefore, become exposed to hazardous materials, with potentially serious health effects, while Murphy and Elimä (2021) also highlight the use of forced labour in PV production chains. At the source of extraction, Aranoff *et al.* (2019) explore how lithium extraction by multi-national corporations in the South American Andes is damaging local ecosytems which, in turn, threaten local indigenous economies, particularly agriculture. This is a common story of industrial and extractive capitalism, but the point here is to show that the low carbon economy is not intrinsically different without regulation and support to prevent economic and labour exploitation.

More broadly, the intersectional patterns of inclusion and exclusion in the existing economic activities will not necessarily be reproduced in the emergent green economy. There is already evidence that women are less able to access better paid jobs in low carbon sectors (Baruah 2017, Clarke *et al*. 2017), and that other vulnerable population groups such as migrants are disproportionately represented in 'dirty' green jobs like waste recycling (see Gregson *et al*. 2016). There is also a question of what kind of work gets valued in the low carbon transition. While women are less likely to access highly rewarded green jobs they are also more likely to do the unpaid, everyday labour of the low carbon economy, household recycling being one example (Wilson and Chu 2019). At the same time in the global north, the ability to engage in unpaid labour beyond the home through volunteering in low carbon initiatives, for example, remains more the preserve of wealthier, older (often retired), White people, and are also more likely to be men (Smith 2011, Aiken 2012, Felicetti 2013, Grossman and Creamer 2017, Creamer *et al*. 2018).

So, it should not be assumed that all green jobs are good jobs in the global north and in the global south; or that the ability to take part in low carbon transition will be equal for everyone within places. Although there is scope for decarbonisation to create new opportunities in deprived regions and communities, as outlined throughout this paper, there are significant concerns that the

multiple potential spatial divisions of low carbon labour will serve to reinforce employment advantages of privileged areas at the expense of less affluent areas. As in previous rounds of restructuring jobs, created in less affluent areas, might be offset by the decline in carbon-intensive sectors, with new jobs not replacing lost jobs in quantity, skill level or pay or suitability for different kinds of workers.

Again, the issue of wider government policies comes into play in terms of labour market regulation, commitments to quality employment and commitments to addressing regional economic and employment inequalities. Indeed, there will be a key role for national and regional governments to avoid the tendency of decarbonisation to reflect or reinforce the existing employment inequalities. This might include initiatives to support low carbon industries or add value to the existing clusters or sites of low carbon job creation. Proactive strategies might seek to distribute higher value economic activity, investing in meaningful pathways to employment for different groups and communities. However, if there is talk of an eco-precariat it is largely because of limited intervention around wages, job security, working conditions and pathways to employment. In other words, the issue is not that there is a mix of jobs, but rather that disadvantaged groups and communities should not be locked into low paid and low value work. One danger is that maintaining an eco-precariat will be part of attempts to reduce costs of decarbonisation, both reflecting and reinforcing the devaluation of some low carbon job sectors. A green workfare strategy, for example, might provide a significant reserve army of labour for the expansion of informalised dirty jobs that sustain the green economy.

Conclusions

This article has advanced the concepts of decarbonising economic geographies and low carbon spatial divisions of labour to examine the potential implications of decarbonisation for uneven geographical development, regional inequalities and labour market (dis)advantage. The theoretical contribution of this paper has been to develop frameworks for understanding issues of regional inequality and labour market disadvantage in relation to decarbonisation. The employment dimension is, we argue, particularly important from the perspective of just transitions, but so far, it has been underdeveloped in analytical work on the low carbon economy. We have found it particularly useful to frame decarbonisation within the literature on economic restructuring of the 1980s and 1990s, drawing on concepts such as spatial divisions of labour, as advanced by Doreen Massey (1984).

The article has set out a framework for understanding how carbon restructuring might impact spatial structures of economic development and specifically whether there is the potential to create new employment pathways for disadvantaged areas and communities, for example, in relation to new resource geographies of renewable energy generation and the manufacture of cleantech equipment. These opportunities will not necessarily reverse the tendency for higher skilled employment within supply chains to be located in more affluent regions with an existing R&D base, but the spatial dependence of some aspects of low carbon restructuring does create opportunities to build skills and R&D capacities in less favoured regions within a relatively stable growth and investment framework. In that respect it is important to explore and understand the contingent relationship between decarbonised economic geography and the existing spatial structures of regions and localities, including the outcomes of potentially intense spatial competition for new economic activity and the role of government investment in shaping economic possibilities for different places. As such, the broad notion of spatial divisions of labour is particularly relevant to interrogating the fine-grained socio-economic impacts of decarbonisation. This includes questions about whether contemporary restructuring in sectors such as decarbonisation might help flesh out and develop the notion of spatial divisions of labour in the context of intensified outsourcing and global supply chains.

Above all, the paper provides further evidence of the importance of state intervention and investment in mediating processes of economic restructuring. Some disadvantaged communities and

individuals will benefit from the economic churn of decarbonisation, but the geographical distribution of employment opportunities will be shaped fundamentally by the patterns of infrastructural investment and provision of bespoke training and employment schemes that can attract and hold down low carbon economic activity in disadvantaged places. There will be a key role for national and regional governments to mediate the tendency of decarbonisation to reflect and perhaps reinforce the existing employment inequalities. This might include initiatives to support low carbon industries or add value to the existing clusters or sites of low carbon job creation. This complements more recent work on Global Production Networks of decarbonisation (see e.g. Hughes and Quitzow 2018) by drawing attention to relational interplay between spatial divisions of labour and local labour/economic development regimes.

There are other factors that might shape employment outcomes of decarbonisation. Automation of work, for example, will have fundamental implications for the number of jobs available, their quality and spatial distribution. Automation will also alter the landscape of employment advantage and disadvantage. However, a central argument of this paper is that it is possible to start planning now for future low carbon economic restructuring, and that doing so could help meet the twin goals of addressing employment inequalities and supporting low carbon transitions. This is especially important in the post-COVID19 economic recovery that might provide a platform for a stronger emphasis on the employment generation potential of decarbonisation.

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