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Does climate action destroy jobs? An assessment of the employment implications of the 2-degree goal

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Abstract. *The Paris Agreement lays out the objective of keeping global warming below 2°C. The goal can be achieved by increasing both the share of renewables in the energy mix and energy efficiency. Such action entails a transformation of the energy sector, which, given its linkages with the rest of the economy, will have a knock-on effect on other sectors. Using scenarios based on a multiregional input–output database, this article explores the economy-wide and worldwide employment impact of such a transition. Findings suggest that by 2030 most economies will experience net job creation and reallocation across industries. Job creation is driven by the construction, manufacturing and renewables sectors.*

Climate change is one of the defining challenges of our age. There is scientific consensus on the reality of humanity's interference in the Earth's atmosphere, which has led to an unprecedented increase in the Earth's average surface temperature and a change in the climate system (IPCC, 2013 and 2014a; Steffen, Broadgate et al., 2015; Steffen, Richardson et al., 2015). The Intergovernmental Panel on Climate Change (IPCC) highlights the many, mostly negative, effects of climate change on the environment, societies and the economy; and it has been suggested that the burden of these effects will fall mostly on vulnerable countries and population groups (ILO, 2018; IPCC, 2014a and 2018). The Paris Agreement, as part of the United Nations Framework Convention on Climate Change (UNFCCC), has been ratified by more than 180 countries. It calls for aggressive action to keep the rise in global temperatures from pre-industrial levels below 2 degrees Celsius (°C) in the long term.

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Action to limit climate change is hampered by the fact that benefits are felt in the long term, while the costs are felt today. Nor is it aided by the fact that those responsible for inducing climate change are not the ones who will be burdened by its consequences (Stern, 2007). Indeed, real or perceived short-term costs in terms of gross domestic product (GDP) growth and employment may discourage the adoption of climate action, even if it would result in long-term benefits (Brekke and Johansson-Stenman, 2008).

Given the importance of employment in the political economy of climate change (Babiker and Eckaus, 2007), this article addresses the employment implications of the 2-degree objective. Does taking globally coordinated action that would effectively limit global warming to 2°C create employment opportunities or job losses in the medium term? Will this transition entail a reallocation of employment across industries? And are economies ready for these structural changes? In analysing a scenario that achieves the 2-degree objective, we find that employment effects are small for most economies. In all, more jobs will be created than destroyed and a certain reallocation of jobs is expected. In identifying the industries and economies that will experience job losses and reallocation, this article highlights the specific areas for policy action to ensure that a transition to sustainability is also a just transition.

The remainder of the article is organized into four sections. In the first section, we describe how climate action impacts employment across the global economy, noting that complementary areas of policy change are needed for climate action to be employment-friendly. The second section describes the data and methods used to estimate the medium-term impact of climate action on employment. In the third section we present our results, and in the fourth section we discuss these results and provide our conclusions.

The low-carbon transition and employment

Economies are currently heavily reliant on the emission of CO_2 and other greenhouse gases (GHGs) in order to meet their energy and product demand (IPCC, 2013 and 2018; Steffen, Broadgate et al., 2015).[1] According to the IEA (2016a) and the World Bank World Development Indicators database, despite a reduction in GHG intensity over the past 25 years (in 1990, 0.82 kg of carbon dioxide equivalent (CO_2-eq) GHGs were emitted for every 2011 purchasing power parity (PPP) dollar of GDP; in 2014 this had been reduced to 0.48 kg), total GHG emissions grew from 39 to 54 gigatons of CO_2-eq, on ac-

[1] Energy demand is the main source of GHG emissions across the world. Taking action in the energy sector alone would help achieve the 2-degree goal (IEA, 2015). Industrial processes are another significant source of GHGs, while an important source of climate change is the reduction of the biosphere's ability to absorb GHG emissions, notably owing to land use change (IPCC, 2013).

count of GDP growing faster than reductions in GHG intensity.[2] GHG emissions stand far above the Earth's capacity to sequester these gases, producing climate change (IPCC, 2013).

Further reducing the carbon intensity of economic activity to bring about a decrease in overall emissions is a fundamental element of a climate-friendly economy (idem, 2014b; Ward et al., 2016). Given that energy is one of the primary sources of GHG emissions (IPCC, 2014b and 2018), advancing a climate-friendly economy is underpinned by the promotion of energy efficiency, on the one hand, and increasing the share of energy sources that do not emit GHGs, on the other.[3] This is largely acknowledged in the nationally determined contributions submitted by signatories to the Paris Agreement (IRENA, 2017; UNEP, 2017) and by different agencies providing advice with respect to specific measures for the energy sector (DDPP, 2015; IEA, 2015 and 2017; IPCC, 2014b).

The International Energy Agency (IEA, 2015) lays out a path for the transition towards renewable energy sources and an increase in energy efficiency to achieve the 2-degree goal.[4] At the worldwide level and compared to a business-as-usual path that would lead to global warming of approximately 6 °C, the IEA's 2-degree path proposes a 55 per cent global reduction in electricity generated from coal, a 26 per cent global reduction in electricity generated from natural gas and a 13 per cent global reduction in electricity generated from oil. The 2-degree path also projects an increase in electricity generated from renewables such as geothermal, wind, solar photovoltaic and nuclear energy and hydropower (globally at 75, 75, 59, 46 and 16 per cent, respectively), among other sources. It also projects a 9 per cent reduction in the total electricity generated due to enhanced energy efficiency. Table 1 outlines the expected differences in energy demand by energy source between the business-as-usual scenario and the IEA's scenario to achieve the 2-degree goal.

A shift away from fossil fuels and towards renewables and energy efficiency will undoubtedly affect employment in the energy sector, given that the amount of labour needed to obtain a similar output differs according to the

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[2] Carbon dioxide (CO_2) is the largest contributor to GHGs which, in turn, are responsible for climate change. Other GHGs include methane, nitrous oxides and F-gases (HFCs, PFCs and SF_6). For the sake of simplicity, non-CO_2 GHGs are converted to a CO_2 equivalent (CO_2-eq) based on their global warming potential (GWP). For example, nitrous oxide (N_2O), emitted during agricultural and industrial activities, has a GWP of 298 times that of CO_2. F-gases, commonly used as refrigerants or fire suppressants and in various industrial processes, have a GWP ranging from 124 for some specific hydrofluorocarbons, to 22,800 for sulphur hexafluoride. Energy-related emissions consist largely of CO_2.

[3] A low-carbon economy also requires the reduction of non-energy related GHGs, such as emissions from industrial or agricultural processes. It can also entail the promotion of carbon sinks (e.g. reforestation and afforestation) or the development of technology to capture and store GHG emissions. As more than 50 per cent of these emissions result from energy demands, a low-carbon economy cannot take place without specific attention to the energy sector (IEA, 2015).

[4] In the Paris Agreement, countries pledge to follow their nationally determined contributions (NDCs) to achieve the 2-degree goal. The analysis in this article focuses on the IEA and the path it proposes to achieve that goal (IEA, 2015). We do not focus on the NDCs because a gap remains between what can be achieved with the currently defined NDCs and the 2-degree goal (UNEP, 2017).

Table 1. Changes in energy demand by energy source by 2030 under the 2-degree scenario (percentages)

	OECD economies	Non-OECD economies
Total primary energy demand	–17	–19
Renewables	50	29
Fossil fuels and nuclear	–28	–29
Total fuel input electricity and heat generation	–9	–19
Renewables	45	52
Fossil fuels and nuclear	–23	–31
Total final energy demand from transport	–27	–30
Fossil fuels and nuclear	–34	–36
Total construction, agriculture, fishing and other	–15	–14
Fossil fuels and nuclear	–29	–27
Total gross electricity generation	–6	–11
Renewables	40	49
Fossil fuels and nuclear	–39	–38

Source: IEA, 2015.

energy source. Moving towards energy sustainability will imply a reallocation of labour across energy sub-sectors and will affect total employment in the energy sector. Wei, Patadia and Kammen (2010) find that the labour intensity of electricity generated from renewables is higher than that of electricity generated from fossil fuels. For example, for each gigawatt hours (GWh) generated, electricity from solar photovoltaic energy requires 0.87 total person-years, while electricity from coal or natural gas requires 0.11 total person-years. This explains why the recent growth in the share of renewables is linked to an increase in employment in the electricity sector worldwide (Montt, Maître and Amo-Agyei, 2018).

Yet the effects of adopting renewables and increasing energy efficiency imply a structural change that goes far beyond the energy sector itself, shifting demand for products and services throughout the economy (Bowen, Duffy and Fankhauser, 2016; Bowen and Kuralbayeva, 2015). Indeed, the energy sector is closely linked, through forward and backward linkages, to many other industries. Changes in the energy sector – through changes in electricity generation, transport and construction – will necessarily also touch other sectors. In the case of energy in the automotive sector, for instance, electric vehicles entail very different technologies, inputs and value chains when compared to internal combustion engine vehicles, altering the forward- and backward-linked industries. The electrification of automotive vehicles changes the demand for inputs and the final demand for oil products, and shifts consumer spending patterns (UBS, 2017).

These indirect effects have employment implications. The electricity sector is one of the sectors with the highest employment multipliers in the economy (WEF, 2012). In the United Kingdom, for example, for each job created in the electric power generation, transmission and distribution sector in 2010, 5.27 jobs were created in other sectors, ranking it fourth out of 127 economic sectors (the extraction of crude petroleum and natural gas, and mining of metal ores are the sectors with the highest employment multipliers, at 10.1).[5] In Scotland, the employment multiplier of the electricity sector in the 1998–2015 period was 2.7.[6] Garrett-Peltier (2017) shows that a spending increase of US$1 million in the renewable energy sector creates 7.49 full-time equivalent jobs; a similar spending increase in the fossil fuel industry supports 2.65 jobs and a similar spending increase in energy efficiency supports 7.72 jobs (see also Cassar, 2015; OECD, 2009; Stehrer and Ward, 2012).

Given these linkages, the employment effects of any change in the energy sector are not restricted to the sectors directly involved. Indeed, on a worldwide scale, a shift from fossil fuel-based energy towards renewables and increased energy efficiency creates employment in the construction and renewables sectors, but also in the manufacturing of electrical parts and in the mining of copper ores. On the other hand, the shift reduces employment opportunities in fossil fuel-related sectors, such as coal mining, petroleum refinery and refuelling stations (Fragkos and Paroussos, 2018; ILO, 2018; Mercure et al., 2018; New Climate Economy, 2018).

The net employment effect resulting from changes in the energy sector to achieve the 2-degree goal indicates the total number of jobs created. Though informative, it is a limited measure of employment impact. It does not capture excess job reallocation between industries, or how jobs move from one industry to another (Davis and Haltiwanger, 1992). Accordingly, for each economy, the total effect on employment (creation, destruction and reallocation across industries) will depend, first, on the extent to which the energy sector needs to shift towards renewables and increased energy efficiency; second, on the linkages between the energy sub-sectors affected and other industries; third, on the labour intensity of the sectors that gain and lose activity; and, last, on the extent to which inputs to achieve the transition are sourced internally or imported.

Climate action and the transition to energy sustainability can thus lead to significant economic and employment changes. Whatever the effect on employment across industries, an economy requires solid institutions, adequate industrial policies, regulations and the capacity to achieve structural change for it to be employment-friendly (Salazar-Xirinachs, Nübler and Kozul-Wright, 2014). Institutional preparedness guides structural transformation, setting the framework for local action (Acemoglu, Johnson and Robinson, 2001; Lehtonen, 2004; Sokoloff and Engerman, 2000) and, in the specific case of employment,

[5] See UK Office for National Statistics: "Type I UK employment multipliers and effects by SU114 industry group and sector (market, government, NPISH)", Input–Output Analytical Tables (2010) supplementary analysis, 2014.

[6] See Scottish Government: "Leontief Type 1 Inverse and Type 1 Multipliers and Effects 1998–2015", 2018.

helps to ensure that workers can satisfy the resultant change in demand for employment (Bowen and Kuralbayeva, 2015). It furthermore enables the protection of workers and firms in particular sectors or regions against any negative impacts in terms of displacement and lower demand (ILO, 2018).

Our results show that the net employment effect is generally positive, but small, and that an excess job reallocation between industries exists, but is also relatively modest in scale in comparison to yearly changes in the economy. These effects are nevertheless non-negligible. This is why our article goes on to link these employment changes to the broad and institutional characteristics of each economy, seeking to identify the characteristics that best predict employment gains or losses and measure the ability of economies to adapt to the projected employment changes. The data and methods to achieve these results are discussed in the following section.

Data and methods

We begin by constructing global, economy-wide scenarios of technology and demand change: one for a baseline (business-as-usual) and another that would achieve the 2-degree goal of the Paris Agreement. We then perform a comparative analysis of the two scenarios to estimate the economy-level net employment creation and job reallocation across industries. We lastly explore the economy-level characteristics associated with those outcomes and analyse institutional preparedness to adopt policies that advance the 2-degree objective and positive employment outcomes simultaneously.

The scenarios are built on EXIOBASE, a multi-regional input–output (MRIO) system that reports the interlinkages between final consumption, the flow of intermediate and final goods, and production-factor inputs. The environmental and socio-economic extensions to this database allow the analysis of the corresponding impacts along global value chains resulting from changes in global production networks. Its latest version, EXIOBASE 3, covers 163 industries (for the symmetric input–output tables) and 200 products (for the supply-and-use tables) across 44 economies and five rest-of-the-world regions.[7] Among other environmental and socio-economic extensions, EXIOBASE 3 reports on total employment, female employment, employment by skill level, vulnerable employment, and total GHG emissions for each sector in each economy.[8] Tukker et al. (2013), Wood et al. (2015) and Stadler et al. (2018) provide more information on EXIOBASE 3 and its potential uses. A detailed description of the labour accounts in EXIOBASE 3 can be found in the on-

[7] Table A2 in the Appendix provides a list of the 163 industries in EXIOBASE 3. The table also lists how each of these industries is aggregated into the broader sectors of agriculture, mining, manufacturing, fossil fuels and nuclear, renewables, utilities, construction, services and waste management. Except where noted explicitly, analysis in this article generally draws on the 163 industry classification.

[8] EXIOBASE is available through the project's website: www.exiobase.eu [accessed 30 Oct. 2018].

line supporting information provided by Stadler et al. (2018). One of the major advantages of EXIOBASE 3 for the analysis of the 2-degree objective is its highly detailed focus on the electricity and resource extraction and resource use sectors (modelling 11 different electricity generators and delineating all major primary fuels).

EXIOBASE 3 provides time series of data from 1995 to 2016, with progressively decreasing amounts of data (more recent data are "now-casted", see Stadler et al., 2018). For the scenarios used in this study, we take 2014 as the base year, which is the last year for which detailed trade data have been incorporated. We project the 2014 data set to 2030, combining the International Monetary Fund (IMF) GDP projections to 2022 with the IEA regional growth projections to 2030 (IMF, 2017; IEA, 2016b). Except for the changes modelled in the scenarios (described below), the basic trade and country-specific sectoral structure of the world economy remains as described by the 2014 data in EXIOBASE 3 (Wiebe et al., 2018).

Identifying indirect effects

For energy and all other sectors, MRIO tables record the flow of intermediate goods and services in the world economy and, in so doing, map the inter-industry linkages in the global economy. Analyses based on MRIO systems capture how changes in one specific industry, such as the electricity generation sector, produce employment effects in the electricity generation industry itself (i.e. direct effects) and changes in other upstream or downstream industries, such as coal mining (i.e. indirect effects). This logic can be extended to the estimation of effects on industry-specific environmental impact (e.g. GHG emissions).

Using the common input–output notation, the indirect employment effect of one production unit of final goods of industry j is calculated as:

$$\underbrace{e_j^{ind}}_{\text{indirect}} = \underbrace{\mathbf{e}'\mathbf{L}\mathbf{i}_j}_{\text{total}} - \underbrace{e_j}_{\substack{\text{direct} \\ \text{employment}}} \tag{1}$$

where $\mathbf{e}$ is a vector of direct employment per unit of output for all industries, $\mathbf{L}$ is the Leontief inverse, $\mathbf{i}_j$ is a vector where all entries are equal to zero, except the entry corresponding to industry j, which equals 1, and e_j is the direct employment per unit of output of industry j.

Modelling scenarios in EXIOBASE

An energy-sector scenario that achieves the 2-degree goal implies a series of mostly exogenous changes in final demand and production structure, or technological change (De Koning et al., 2016; Wiebe, 2016). The 2-degree scenario affects many different industries and parts of the economy. It requires investment in the adoption of new technologies, which have to be purchased, and it changes final and intermediate demand when these technologies are used. As described by Wiebe (2018), in an input–output framework, both the economic structure and technology are represented as the intermediate input coefficients. But modelling technological change in an economy by changing the input coefficients alone is not sufficient. Wiebe (2018) explains how to model technological change consistently in a forward-looking multi-regional input–output model and, to that end, differentiates between the following five types of changes regarding parts of the input–output system (input–output table (IOT) changes): (1) gross fixed capital formation; (2) input coefficients for technology production; (3) input coefficients for technology use; (4) emissions and employment intensity of production (or any other relevant environmental or socio-economic extension), and (5) value added shares, including compensation of employees.[9]

This model can be applied to IOTs in which the electricity sector is represented as an aggregate sector. This is the case of MRIO systems such as the Global Resource Accounting Model (GRAM) (Wiebe et al., 2012) used by Wiebe (2018), the OECD Inter-Country Input–Output (ICIO) Tables (Wiebe and Yamano, 2016) or the World Input–Output Database (WIOD) (Timmer et al., 2014). In EXIOBASE 3 (Stadler et al., 2018), which is used for the analysis in this article, the electricity industry is disaggregated into 11 different technologies. For our scenarios, we have therefore changed the demand (final and intermediate) for the different types of electricity according to the shares assumed in the IEA 6-degree and 2-degree scenarios. This results in changes in the inputs needed for the overall electricity sector, and the emission intensity of the average electricity generation (IOT changes 3 and 4), and changes in value added and industry output in other sectors because of changing final and intermediate demand patterns (IOT change 5). All the changes described here are implemented in the national supply-and-use tables, which are then linked into the global system using product-level import shares that do not change over time. For the subsequent conversion to symmetric IOTs for the Leontief inverse (equation 1), the industry technology assumption is used.[10]

The following are some key assumptions, common to all MRIO scenario exercises:

- Prices are not endogenized, in other words, relative prices between products and economies do not change. Changes in relative prices resulting from technological change would lead, for example, to changes in the production structure and production locations through substitution or complementary effects.
- All changes implemented in the model are exogenous, implying that systemic rebound effects, such as macroeconomic price or growth effects, are not taken into account.[11]
- Market shares and bilateral trade shares remain constant.

[9] See Wiebe (2018) for an illustration of these changes using the example of increasing electricity production using wind turbines.

[10] Assumes that all products produced by an industry are produced with the same input structure.

[11] Gillingham et al. (2013) argue that rebound effects are generally small.

Although these assumptions may be considered to be limitations, our scenario approach provides more modelling detail (regional, sectoral and technological) than other approaches that would incorporate these issues in the model.[12] The MRIO scenario results presented in this article (first-order impacts) are, furthermore, devoid of the effects of assumptions about substitution elasticities, utility and profit maximization, and price equilibrium, among others.

The scenarios

The IEA has developed a 2-degree scenario for the decarbonization of the world economy and a 6-degree, business-as-usual, scenario. The former would sufficiently reduce GHG emissions to limit global warming to 2 °C above the pre-industrial average, while the 6-degree scenario is largely a continuation of current trends (IEA, 2015).

The IEA scenarios are based on four interlinked technology models for the energy generation sector (energy supply) and the construction, industry and transport sectors (final energy demand). The modelling framework specifies paths for 39 world regions or economies, including OECD and non-OECD economies, economies of the Association of Southeast Asian Nations (ASEAN), Brazil, China, the European Union (EU), India, Mexico and the Russian Federation.

The 2-degree scenario lays out an energy system pathway (for the energy supply and demand side), which is consistent with an emissions trajectory that limits the average global temperature increase to 2 °C. This scenario limits the atmospheric concentration of GHGs to 450 parts per million. One way to achieve this concentration or the 2°C target is to reduce global CO_2 emissions from the energy sector. Emissions would need to be cut by 20 per cent by 2030 and by 60 per cent by 2050 compared to 2012 emissions. This means reducing the 34 gigatons of CO_2 emissions recorded in 2012 to 27 gigatons in 2030 and to 14 gigatons in 2050.

The 2-degree scenario identifies changes to the energy supply system, mapping five-year targets from 2020 to achieve the emissions reduction goal by 2050. By 2030, this transition means, most notably, that CO_2 emissions would have to be 39 per cent lower by 2030 than the emissions in the business-as-usual scenario. This entails, on the one hand, a transition to renewable energy technologies that help ensure secure and affordable energy in the long run and, on the other, increased efficiency across industry, transport and construction. In this regard, by 2030, total energy demand for these three sectors would drop by 20, 29 and 14 per cent, respectively, when compared to the business-as-usual 6-degree scenario.[13]

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[12] The data used in this article and by Wiebe et al. (2018) are available at: https://doi.org/10.5281/zenodo.1342557 [accessed 30 Oct. 2018]. The code used by Wiebe et al. (2018), which we adapt, is available at: https://github.com/kswiebe/FEMRIOv1_EXIOfuturesIEAETP/ [accessed 30 Oct. 2018].

[13] By 2050, the 2-degree scenario entails 74 per cent lower CO_2 emissions than the business-as-usual scenario, and a 30, 44 and 28 per cent lower energy demand in the industry, transport and construction sectors, respectively.

The business-as-usual scenario is largely an extension of current trends in emissions and fossil fuel use for primary energy demand. No major technological change is modelled on the assumption that no new policies will be adopted to limit global warming. Table 1 sets out the broad energy source changes that could achieve the 2-degree scenario by 2030, compared to the 6-degree scenario, for OECD and non-OECD economies.

According to the estimates of the IEA (2015), in order to achieve the 2-degree goal, a total of US$358.8 trillion capital investments are required by 2050. This is US$40 trillion more than is required in the 6-degree scenario (US$318.4 trillion). The following average annual capital investments are needed up to 2050 to achieve the 2-degree goal:

- US$1 trillion in the power sector (renewable electricity and heat generation technologies, transmission and distribution);
- US$0.8 trillion in the construction sector (including heating, cooling and other end-use technologies, and energy efficient building insulation, such as windows, roofs and seals);
- US$0.3 trillion in the industry sector (including energy efficiency technologies in iron, steel, chemicals, cement, pulp and paper, and aluminium industries); and
- US$8.1 trillion in the transport sector (including in mass transport systems and vehicle electrification).

Importantly, under the IEA's 2-degree scenario, accumulated fuel cost savings over the period 2016–50 are estimated at around US$115 trillion, more than offsetting the additional capital investments of US$40 trillion. Non-OECD member economies account for the majority of additional investments required and savings achieved, pointing to strong demand growth in emerging economies.

In this study, we use the four energy technology system transformations put forward by the IEA to model the structural change of the world economy in the MRIO. We estimate changes in capital investments, energy supply, and intermediate and final energy demand by industry. We assume that GDP growth will shift towards the four modelled low-carbon industries and that the additional US$40 trillion investments that are required by the 2-degree scenario will be financed through the expected savings of US$115 trillion. Aggregate projected GDP growth in the two scenarios converges by 2030, while growth rates at the industry and economy levels follow the scenario specifications. We then project the MRIO up to 2030 for the 2-degree scenario.[14]

[14] There are infinite other scenarios to achieve the 2-degree goal by 2050, including those that assume lower or zero economic growth in developed countries (e.g. Victor, 2012), compared to the projections under the IEA scenario. Scenarios proposed by the Deep Decarbonization Pathways Project (DDPP) largely follow the one used in this article in that they promote the use of renewables and energy efficiency. They are robust to different specifications and investment pathways (DDPP, 2014 and 2015).

The two scenarios change very few components in the MRIO system. They should therefore be analysed relative to each other and not in absolute terms in order to assess the changes that may come about from the differences in the scenario specifications. We thus compare results from the 2-degree scenario to those from the 6-degree scenario with no technological change.

Net employment change and between-sector excess job reallocation

The model provides the total employment projected in 2030 in the 2-degree and 6-degree scenarios for each of the 163 industries in EXIOBASE 3, for each of the 44 economies and five rest-of-the-world regions. For each economy, we estimate the net employment change between the two scenarios. We also estimate the excess job reallocation between industries associated with the 2-degree scenario, following Davis and Haltiwanger (1992). While net employment change measures the total number of additional (fewer) jobs in the 2-degree scenario compared to the 6-degree scenario, between-sector excess job reallocation measures movements from one of the 163 industries in EXIOBASE 3 to another. To better understand the magnitude of the change, we also discuss the labour intensities of the industries most affected by the 2-degree scenario.

Formally, net employment change (*netemp*) for a country (*c*) is the change between the employment level (*e*) projected in the 2-degree scenario across all 163 industries (*i*) and the employment level projected in the 6-degree scenario. A positive (negative) value indicates the proportion by which employment in the 2-degree scenario will be higher (lower) than in the 6-degree scenario. Net employment change is thus defined as:

$$netemp_c = \frac{\sum_{i \in s} e_{c,i}^{2DS} - e_{c,i}^{6DS}}{\sum_{i \in s} e_{c,i}^{6DS}} \qquad (2)$$

The net employment change does not capture all the employment changes involved in the 2-degree scenario compared to the 6-degree scenario. Theoretically, a net employment change of zero is compatible with a considerable change in employment, in so far as it would be possible for no net jobs to be created or destroyed in the aggregate, while jobs could move from one industry to another.[15] This movement of jobs across industries is the excess job reallocation (Davis and Haltiwanger, 1992). It can be calculated as the difference between total net employment change (equation 2) and the total

[15] Another component of employment shifts consist of within-sector job reallocation, as jobs move from one firm to another within the same industrial sector. Though relevant, within-sector job reallocation is beyond the scope of this study as the larger share of the impact of moving towards the 2-degree scenario and away from the 6-degree scenario involves a change between industries (Bowen, Duffy and Fankhauser, 2016).

movement of jobs between the 163 industries in EXIOBASE 3, that is, the reallocation that exceeds the minimum under a given net change:[16]

$$excess_c = \frac{\sum_{i \in s} \left| e_{c,i}^{2DS} - e_{c,i}^{6DS} \right|}{\sum_{i \in s} e_{c,i}^{6DS}} - \left| netemp_c \right| \tag{3}$$

In order to explore the mechanisms underlying the magnitude of changes in a given sector–country pair, we discuss the labour intensity of a given sector relative to the country average. The model assumes fixed labour intensities $\alpha_{c,i}$, in other words, a fixed quantity of employment per unit of added value in all scenarios:

$$e_{c,i}^{S} = \alpha_{c,i} \, y_{c,i}^{S} \tag{4}$$

where $y_{c,i}^{S}$ is the value added of industry i in country c. A measure of relative labour intensity can therefore be computed for a given sector–country pair, given by:

$$\check{\alpha}_{c,i} = \frac{e_{c,i}^{DScenario} / \sum_{i \in s} e_{c,i}^{6DS}}{y_{c,i}^{DScenario} / \sum_{i \in s} y_{c,i}^{6DS}} \quad DScenario \in (2DS,\, 6DS) \tag{5}$$

To explore whether certain economies are more prone to experience higher (or lower) net job creation and between-sector excess job reallocation, we link these employment outcomes to characteristics of the economy. Such aggregate characteristics, extracted from the World Bank World Development Indicators database, include GDP per capita and the economy's reliance on natural resource rents (expressed as a percentage of GDP), patents per capita, and initial employment shares for each (aggregate) economic sector. As the energy transition affects some specific industries both directly and indirectly, we are able to ascertain whether broad structural attributes related to development and diversification can predict the impact of the transition on employment. Specifically, in a regression analysis, these variables allow us to evaluate whether the development status, natural resource rent share or employment structure of economies predict the level of job creation or between-sector excess job reallocation, and to determine whether certain economies face structural disadvantages with respect to the energy transition.

Finally, we also explore institutional preparedness for changes to the levels and distribution of employment across sectors. Institutions play a determinant role in economic development (Acemoglu, Johnson and Robinson, 2001) by facilitating structural transformation (Salazar-Xirinachs, Nübler and Kozul-Wright, 2014) and enhancing the response to climate change (Agrawal, 2008). The World Bank Worldwide Governance Indicators capture institutional char-

[16] Given its very nature, this metric might be biased upward when computed for the rest-of-the-world regions. Consider the hypothetical case of a region composed of two countries. Let us suppose country 1 experiences an employment loss in a sector i, while country 2 experiences a gain of a similar magnitude in the same sector i. Computed at the country level, these changes would tend to reduce $excess_c$ in both 1 and 2. If instead we compute the metric at the regional level, the changes will cancel each other out.

acteristics on the basis of firm and household surveys, and expert assessments carried out by NGOs, and multilateral and other organizations (Kaufmann, Kraay and Mastruzzi, 2011). We focus on government effectiveness, which is one of the Worldwide Governance Indicators, capturing the perceived effectiveness of the civil service and public services, the quality of policies and their implementation, and the credibility of governments' commitment to such policies. Effective governance, as an element of an economy's institutional capacity, may be important in the context of structural transformation, in meeting the demand for new skills (in the case of employment creation), offering displaced workers protection and mobility opportunities (in the case of employment loss), and bringing about an effective reorganization of the economy (in the case of job reallocation across industries and employment creation).

Results

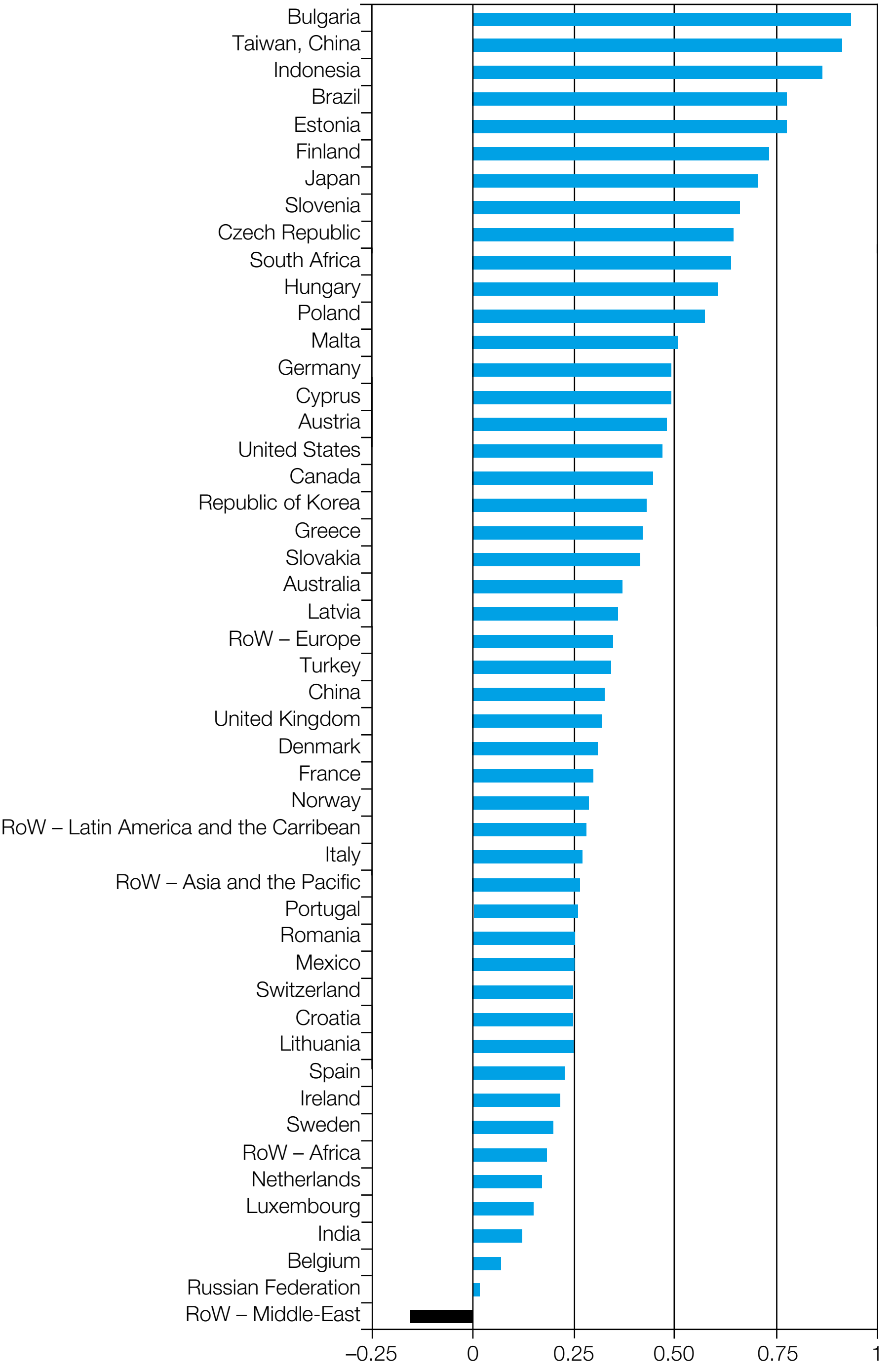
According to our estimation, adopting the measures projected by the IEA (2015) to limit long-term global warming to 2°C will result in approximately 0.3 per cent more net jobs worldwide in 2030, when compared to a business-as-usual scenario (6°C). Relative to global annual changes in employment, this net employment change is small. Over the 2005–17 period, the annual change in employment across the world averaged 1.2 per cent.[17] In the 2-degree scenario no economy has an expected net job creation of more than 1 per cent compared to the baseline. Overall, an 18 million net job creation could be expected under the 2-degree scenario.

Figure 1 shows these percentage differences at the economy level. Of the 44 individual economies analysed, all experience net job creation, with Bulgaria, Taiwan (China) and Indonesia topping the list (all around 0.9 per cent). The economies that are projected to experience comparatively high net job creation under the 2-degree scenario are generally economies that still have to make significant efforts to increase the share of renewables in their energy mix and improve energy efficiency in order to advance sustainability in the energy sector. Indonesia and Taiwan (China), for example, still rely heavily on fossil fuels to meet their energy demands. Some of them are also economies with an industrial structure that will contribute to satisfying the demand for new goods related to energy efficiency and renewables (e.g. Taiwan (China) and Bulgaria).

As regards jobs, and very much in relation to the size of these economies, the difference in net job creation between the scenarios is of approximately 4.9 million in China, 2.1 million in Indonesia, 1.3 million in India and 1 million in the United States.

[17] Authors' calculation based on ILOSTAT.

Figure 1. Net employment change by 2030 under the 2-degree scenario (percentages)



Notes: Net employment change is measured against the 6-degree scenario baseline, as share of 6-degree scenario total employment. Absolute numbers associated with these changes are available in table A1 in the Appendix.

Source: Authors' calculations based on EXIOBASE 3.

Of the five rest-of-the-world regions, the Middle East may experience net job losses and the African region[18] is expected to experience a small net job creation, which may not be different from no change at all. These regions may not benefit from the transition because of their heavy economic reliance on fossil fuels and because of the fact that the industries that are expected to grow in a 2-degree scenario are less developed in the region.

It is important to note that we use the current economic and trade structure of economies' or regions' industries as the basis for the projection. For example, sub-Saharan African economies with a small or non-existent renewable energy manufacturing industry will grow from a very small base and, in absolute terms, will grow only marginally in low-carbon technologies and output. This is explained by the fact that we assume that no industrial policies will be adopted that will alter trade structure or tap into sub-Saharan Africa's significant renewable energy export potential. Indeed, the continent has the potential to source an additional 10 terawatts of solar energy, 1,300 gigawatts of wind power and 7–15 gigawatts of geothermal energy (APP, 2015).

At the industry level, as already noted by the ILO (2018), the 2-degree scenario increases demand for employment in industries such as construction, the manufacturing of electrical machinery, electricity generation from renewables and the mining of copper ores. Of the total 163 industries analysed, 35 could experience employment growth of 100,000 jobs or more, and only eight may experience losses of this magnitude. Job destruction is concentrated in a small number of industries that include, most notably, petroleum refining, the extraction of crude petroleum, the generation of electricity from coal and coal mining.

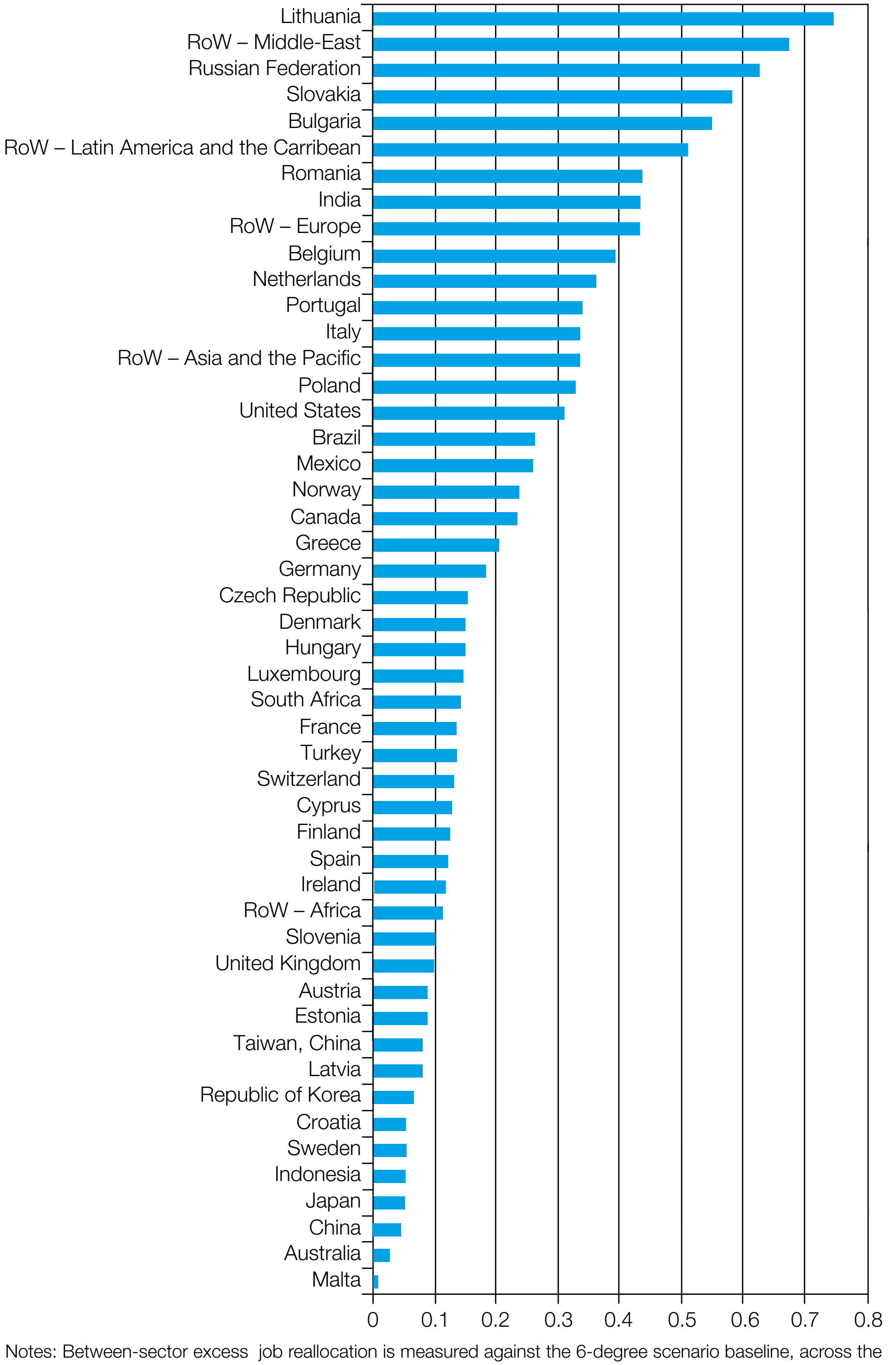
In addition to net employment creation, the transition towards the 2-degree scenario will bring about substantial movement between industries, as certain industries downsize and others grow. In EXIOBASE 3, between-sector job reallocation measures the movement of employment between the 163 industries in each economy. It does not measure employment reallocation within each of these industries, nor within firms.

In total, across the 163 industries and 44 economies, between-sector excess job reallocation amounts to 0.2 per cent of projected employment in 2030. This is equivalent to around 15 million jobs moving from one industry to another.[19] Although the Russian Federation is expected to experience a relatively minor effect, if any, in terms of net job creation, it is predicted to undergo one of the largest reallocations across industries, at a rate of 0.6 per cent (figure 2). In parallel, the estimated excess job reallocation rate for Indonesia is smaller

[18] The rest-of-the-world African region does not include South Africa, which is included as an individual country in the analysis, or North African countries, which are included in the rest-of-the-world Middle Eastern region.

[19] These figures are computed as the sum of the projected between-sector reallocation rates of observed economies and regions. Expressed as a percentage, the sum is divided by the total projected employment in the 6-degree scenario. Excess job reallocation is calculated from the 163 industry classification shown in table A2.

Figure 2. Between-sector excess job reallocation by 2030 under the 2-degree scenario (percentages)



Notes: Between-sector excess job reallocation is measured against the 6-degree scenario baseline, across the 163 industries in table A2 in the Appendix. Absolute numbers associated with these changes are available in table A1 in the Appendix.

Source: Authors' calculations based on EXIOBASE 3.

than 0.1 per cent of projected employment in 2030 – one of the lowest observed, while Indonesia's net employment change is expected to be close to 0.9 per cent. Indeed, the between-sector excess job reallocation rate is weakly and negatively associated with net employment change, partly owing to its construction ($p = -0.35$), as can be see in a comparison of figures 1 and 2. A notable exception is the Middle East, which is projected to experience both a large job loss and reallocation, highlighting the significant employment challenges that the region may face as a result of a worldwide transition to energy sustainability.

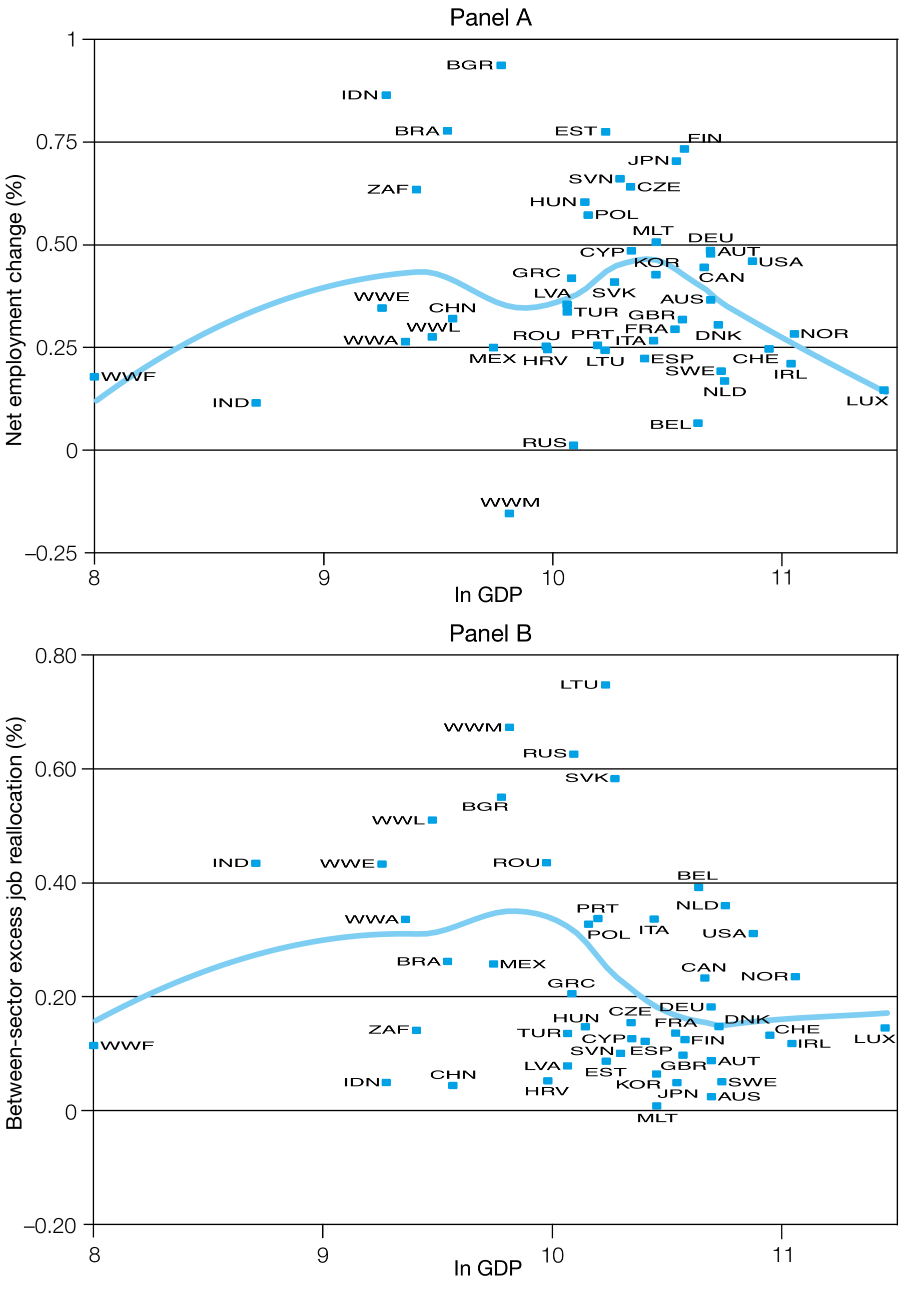
To put these numbers in perspective, between-sector excess job reallocation generally represents 2–4 per cent of an economy's total employment per year (Cahuc, Carcillo and Zylberberg, 2014).[20] From this perspective, the largest ratios of excess job reallocation estimated in this study are only a fraction of typical annual shifts. Like total net employment creation, between-sector job reallocation following a transition in the energy sector is relatively small.

In short, and judging from the direction and size of the changes to net employment and between-sector excess job reallocation, the implementation of policies to reach the 2 °C objective of the Paris Agreement is projected to have a generally positive and relatively small effect on employment.

Net employment change and between-sector excess job reallocation show at best a weak relationship with (log) GDP per capita, signalling that the employment opportunities and employment changes associated with a 2-degree scenario are not confined to developing or developed economies. Figure 3 shows the relationship between (log) GDP per capita in 2016, in 2011 US$ PPP, and expected net employment change (panel A) and between-sector excess job reallocation (panel B). The correlation between (log) GDP per capita and the net employment change, as a percentage, is non-significant ($p = -0.04$). Indeed, economies with similar GDP per capita are expected to experience different net employment change. This is the case, for example, of Lithuania and Estonia; both have similar GDP per capita levels, and yet the estimated net job creation is roughly 0.25 per cent for Lithuania but over 0.75 per cent for Estonia. China and the United Kingdom can expect a similar impact in terms of net employment creation at around 0.3 per cent, but at very different GDP per capita levels (figure 3, panel A). The same is true for excess job reallocation: the expected between-sector reallocation is non-significantly related to (log) GDP and the correlation to (log) GDP per capita is, likewise, statistically non-significant ($p = -0.22$) (figure 3, panel B). This means that economies with similar GDP per capita levels may experience very different excess job reallocation by 2030 as a result of the transition to energy sustainability (e.g. Belgium and Sweden), just as economies that will experience similar levels of reallocation between industries may have different GDP per capita levels (e.g. France and South Africa).

[20] Total excess job reallocation ratios (between and within sectors) are typically between 15 and 25 per cent (Cahuc, Carcillo and Zylberberg, 2014). Between-sector excess job reallocation, according to an industrial sector breakdown used in this study, typically represents 15 per cent of total excess job reallocation (Davis and Haltiwanger, 1999).

Figure 3. Net employment change and between-sector excess job reallocation in the 2-degree scenario vs GDP per capita, 2016



Notes: GDP per capita for 2016, in 2011 US$ PPP. The Pearson correlation between (log) GDP and net employment change (panel A) is non-significant at –0.04; the correlation with between-sector excess job reallocation measured with the 163-industry classification is non-significant at –0.22. Economy names apply ISO 3166-1 alpha-3 letter coding. WWA = rest-of-Asia, WWE = rest-of-Europe, WWF = rest-of-Africa, WWL = rest-of-Latin America and the Caribbean and WWM = Middle East. The fitted curve is obtained through locally weighed scatterplot smoothing.

Sources: Authors' calculations based on data from EXIOBASE 3 and the World Bank World Development Indicators database.

Table A1 in the Appendix summarizes the net employment change and excess job reallocation results by country and region in EXIOBASE 3 as calculated on the basis of the classification of the 163 industries in table A2. It shows the percentage change expected for each of these dimensions of employment change in a scenario of energy transition, and the absolute expected change.

Table 2 explores the linkage between the expected employment change and the characteristics of economies. Given that regions and economies that will experience high levels of job reallocation or relatively less favourable employment effects tend to have sizeable fossil fuel-related sectors (e.g. the

Table 2. Relationship between national economic and structural characteristics and net employment change and between-sector excess job reallocation

	(1)	(2)	(3)	(4)	(5)	(6)
	Net employment	Net employment	Net employment	Excess job reallocation	Excess job reallocation	Excess job reallocation
GDP per capita (log, PPP)	–0.0146 (–0.26)	–0.0661 (–1.18)	–0.212** (–2.47)	–0.0634 (–1.55)	–0.0191 (–0.38)	–0.0538 (–0.75)
Natural resource rent (share of GDP)		–0.0269*** (–4.35)			0.0186** (2.63)	
Patents per capita		0.470 (1.08)			–0.622** (–2.69)	
Share of employment in services			0.00797** (2.31)			0.00343 (1.15)
Share of employment in construction			0.0111 (0.64)			0.00191 (0.11)
Share of employment in utilities			–0.0710 (–1.20)			0.100 (0.86)
Share of employment in fossil fuels and nuclear			0.149 (0.39)			0.0391 (0.10)
Share of employment in manufacturing			0.0235*** (3.74)			0.00871 (1.48)
Share of employment in mining			–0.0267*** (–3.21)			0.0302*** (4.54)
Share of employment in renewables			0.185 (0.59)			–0.186 (–0.73)
Share of employment in waste management			–0.0660 (–1.11)			0.0607 (1.23)
Constant	0.532 (0.92)	1.084* (1.84)	1.724** (2.47)	0.882** (2.06)	0.415 (0.79)	0.290 (0.55)
Observations	48	46	48	48	46	48
R^2	0.002	0.189	0.413	0.047	0.215	0.327

*, ** and *** indicate significance at the 10, 5 and 1 per cent levels, respectively.

Notes: Data for 2016 except for the shares of employment by sector (2014). Each model regresses the national and economic characteristics on the economy's net job creation or excess reallocation observed in figures 1 and 2. Robust standard errors are given between brackets. Dependent variables are expressed as a percentage of the total employment in the business-as-usual (6-degree) scenario.

Source: Authors' calculations based on data from EXIOBASE 3 and the World Bank World Development Indicators database.

Middle East and the Russian Federation), the results in the table explore whether net employment creation and between-sector excess job reallocation are related to other attributes, typically employment structure, economic reliance on natural resources, innovation and economic growth potential. Models 1 and 4 show a baseline regression between (log) GDP and net employment change (model 1) and between-sector excess job reallocation (model 4). The percentage of GDP that is sourced from natural resource rents explains a large part of the variation in the expected net employment change across economies (model 2), but this relationship remains weak. Economies that are more reliant on natural resource rents are somewhat more likely to experience net employment losses or lower net employment creation: a 1 percentage point increase in reliance on natural resources is associated with less than a 0.03 percentage point decrease in net job creation. Economies with a higher share of employment in the manufacturing sector are projected to experience higher net job creation, reflecting the role of the sector in the production of the machinery necessary to achieve the transition. Economies with a higher number of patents (a measure of innovation) will tend to experience lower job reallocation between industries. This is probably explained by the fact that more innovative economies, those that have a relatively higher number of patents, have more employment in sectors that are less likely to be affected by the energy transition (model 6).[21]

Overall, the results shown in table 2 highlight the weak impact of a transition to a 2-degree scenario on employment, despite the fact that the transition involves a structural transformation in the energy sector. Figure 4 shows the change in value added and net employment by industry and economy. For convenience's sake, the 163 industries have been aggregated into nine broad categories: agriculture, construction, manufacturing, mining, services, waste management, and three sectors directly related to energy generation and distribution, namely renewables, fossil/nuclear and utilities.[22] Value added and employment changes are normalized by the economy total:

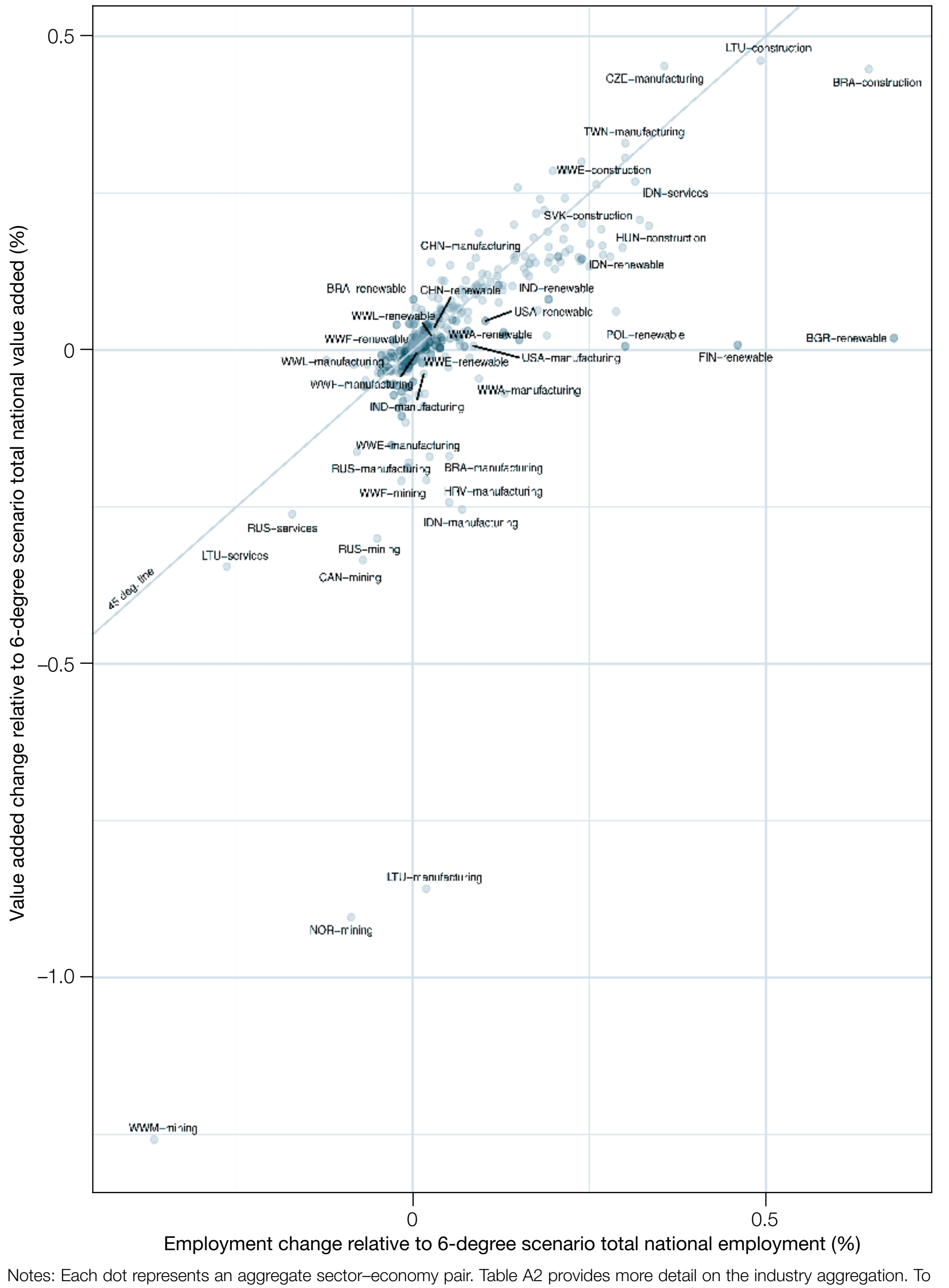
$$(x_{c,i}^{2DS} - x_{c,i}^{6DS}) / \sum_{i \in s} x_{c,i}^{6DS} \tag{6}$$

where $x_{c,i}$ is the value added or employment, respectively. The slope of a line connecting any sector–economy dot to the origin is the inverse of the relative labour intensity ($1/\breve{\alpha}$). The sector's position relative to the 45-degree line is the difference between the sector's labour intensity and the economy's average labour intensity. For example, Brazil's construction sector, which is projected to experience employment growth in the 2-degree scenario, is below the 45° line. This means that the increase in employment in the sector relative to

[21] A higher number of patents may signal that a country's firms have a higher capacity to innovate and adapt to changes in demand, but these adjustment effects are not incorporated into the model presented here. The discussion section provides more details regarding the assumptions and limitations of this methodological approach.

[22] Table A2 in the Appendix provides the details of the aggregation.

Figure 4. Change in value added and net employment



Notes: Each dot represents an aggregate sector–economy pair. Table A2 provides more detail on the industry aggregation. To facilitate exposure, only selected sector–economy pairs are labelled. Economy names apply ISO 3166-1 alpha-3 letter coding. WWA = rest-of-Asia, WWE = rest-of-Europe, WWF = rest-of-Africa, WWL = rest-of-Latin America and the Caribbean and WWM = Middle East.

Source: Authors' calculations based on EXIOBASE 3.

total national employment (on the horizontal axis) is greater than the increase in value added relative to total national value added (on the vertical axis). This is because Brazil's construction sector has a relatively high labour intensity, shown by the fact that relative employment growth outpaces relative value added growth in the 2-degree scenario.

First, the transformation in the energy sector (renewables, fossil/nuclear and utilities) has a small net employment effect because this sector is relatively small in the context of any economy's GDP. For example, the increase in renewables, modelled in the 2-degree scenario, contributes to no more than 0.03 per cent of value added at the global scale.

Second, the sectors that are most affected by the transition have a relatively low labour intensity. The value added effect of the transition is negative, with the greatest effect identified in mining, but the overall effect is small because the sector is characterized by low labour intensity. For example, the sector–economy pair that is the most affected is the mining sector in the Middle East. As a result of the transition, it is projected to reduce its value added by approximately 1.3 per cent of GDP, but this will result in no more than a 0.4 per cent reduction in total employment.

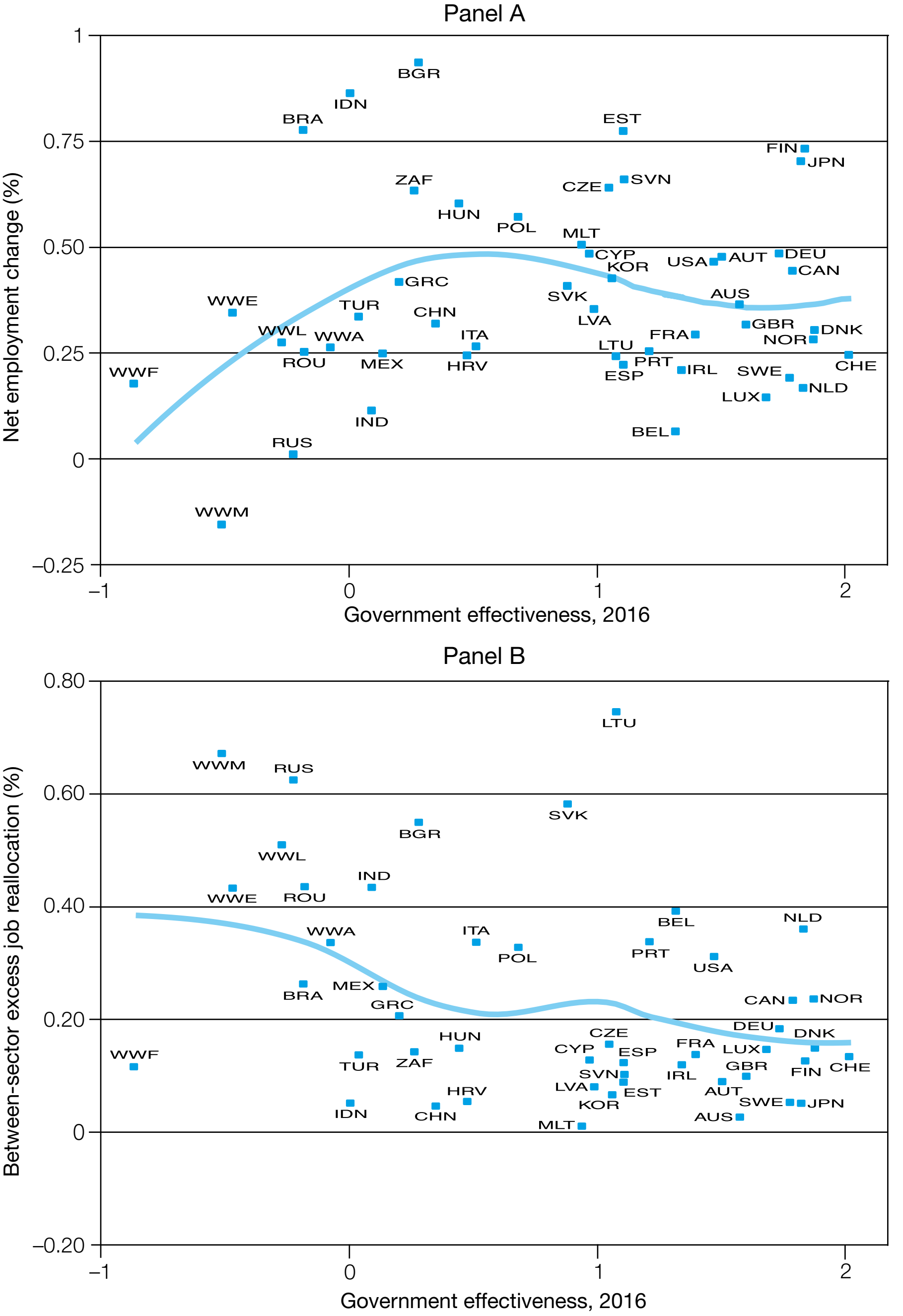
It is worth noting that employment gains are concentrated in sectors supplying intermediary products to the energy generation and energy efficiency sectors: manufacturing and construction. Since the latter is more labour-intensive, it also produces a greater employment change than the former.

Although overall employment effects are expected to be small, they are non-negligible and tend to be concentrated in specific industries and regions. They require an economy to be capable of adapting, reskilling and moving its labour to meet new demand, and of protecting workers and communities that are unable to move. This will allow the transition to be just and protect both workers and firms that may lose out (ILO, 2015). Institutional characteristics such as government effectiveness may facilitate an economy's smooth transition. Strong institutions can enable the rapid implementation of policies aimed at adapting the economy to new environmental regulations, such as reskilling or other active labour market programmes that support an effective reallocation of workers across industries. Strong institutions may also create better linkages between skill development programmes and changing labour demand, allowing skill development to react faster and more efficiently to these changes. They may also allow for a faster and more effective deployment of social protection schemes.

Government effectiveness measures the institutional capacity of an economy.[23] Figure 5 links government effectiveness with the net employment

[23] It captures the perceptions of the quality of public services, the quality of the civil service and the degree of its independence from political pressures, the quality of policy formulation and implementation, and the credibility of the government's commitment to such policies (World Bank Worldwide Governance Indicators). This index measures infrastructure disruption, political instability, quality of bureaucracy, quality of primary education, satisfaction with public services, civil service integrity and trust in government, among others.

Figure 5. Employment creation and excess job reallocation in the 2-degree scenario vs government effectiveness



Notes: Between-sector excess job reallocation measured with the 163-industry classification. Economy names apply ISO 3166-1 alpha-3 letter coding. WWA = rest-of-Asia, WWE = rest-of-Europe, WWF = rest-of-Africa, WWL = rest-of-Latin America and the Caribbean and WWM = Middle East. The fitted curve is obtained through locally weighed scatterplot smoothing.

Sources: Authors' calculations based on data from EXIOBASE 3 and the World Bank Worldwide Governance Indicators database.

creation and excess job reallocation results from figures 1 and 2. Note should be taken of economies and regions with relatively weak institutions that will experience relatively high employment changes. These are economies that may be particularly ill-prepared to adapt to the transition and to benefit from the potential that it can bring. Such economies may not be able to protect workers and firms that may lose out from the transition, and to meet the basic demands to advance a just transition. This is not only the case for the Middle East (WWM) and the Russian Federation but also for Brazil, the rest of Latin America and the Caribbean (WWL), the rest of Europe (WWE), Turkey and the rest of Asia (WWA). Strong institutional capacity may help offset employment losses in the Middle East by diversifying economic activity and creating opportunities in emerging sectors (ILO, 2018). Similarly, effective government may facilitate the movement of workers across industries in the Russian Federation.

Discussion and conclusion

From the perspective of the world of work, environmental sustainability is urgent (ILO, 2018). A transition to environmental sustainability can affect the number and types of jobs in an economy (ibid.). Mitigating climate change through limiting global warming to 2 °C is a key step towards environmental sustainability. It requires, among other measures, taking concerted action in the energy sector to limit its GHG emissions. This involves a shift away from energy sources using carbon-emitting fossil fuels by adopting renewables and an increase in energy efficiency (IEA, 2015; IPCC, 2014b).

Given the strong linkages between the energy sector and the rest of the economy, concerted efforts in the sector to limit global warming to 2 °C will impact other sectors in the economy. For the same reason, employment throughout the economy is also likely to be affected by a shift in the energy sector. In exploring the IEA's (2015) proposed path to limit global warming to 2 °C, this article shows that, in the aggregate, employment changes, as measured by net employment change and excess job reallocation between industries, do exist: they tend to be positive but generally small in magnitude. These changes are consistent with studies identifying the reallocation of labour associated with the shift from fossil fuel-based energy sources to renewables (e.g. Fragkos and Paroussos, 2018). In contrast to studies that focus solely on the move away from fossil fuels and identify negative effects in certain economies (e.g. Louie and Pearce, 2016; Mercure et al., 2018), we find that these negative effects are offset by the employment creation associated with the promotion of energy efficiency (see also Garrett-Peltier, 2017).

Employment effects are concentrated in specific industries. Job destruction is mostly found in industries related to fossil fuels (e.g. coal mining, petroleum refining, generation of electricity from coal and natural gas), prompting the need to offer protection and opportunities to transition to emerging sectors. Job creation is expected most notably in the construction sector, and in the generation of electricity from renewable sources, the manufacturing of electrical parts and machinery, and the mining of copper ore. Skill development will be crucial to meet the increased demand for labour in these sectors. Given that job losses and job creation will not necessarily occur in the same geographical region, mobility incentives might be needed in order to achieve a frictionless reallocation between industries.

Although economies where GDP is highly dependent on natural resources are more likely to experience negative employment outcomes, and those with a higher share of employment in manufacturing are likely to experience greater net job creation, general economic and structural characteristics do not accurately predict the extent and nature of the employment change. This suggests that there are no structural factors constraining or predetermining the outcomes of the transition across economies. The absence of institutional readiness and the ability of economies to guide this transition, absorb the negative employment effects and create the right conditions for the potential job creation could become constraints in advancing an employment-friendly energy transition. This consideration is particularly relevant for developing economies that may have resource constraints for developing this institutional capacity.

These results suggest that, in the political economy of climate change mitigation through energy transformation, employment is not an obstacle to advancing climate action. If anything, the effects are positive for most economies, albeit small. Although change may be important in economic terms, its greatest effects are felt in industries with relatively low labour intensities. Whatever change is expected, it can be made smoother if appropriate policies for a transition to energy sustainability are taken gradually in the run-up to 2030.

The IPCC (2018) has recently noted the benefits of limiting global warming to 1.5 °C, which is an objective encouraged by the Paris Agreement. Achieving a 1.5-degree scenario calls for more aggressive climate action through a faster shift to renewables and accelerated growth of energy efficiency. It also calls for the development of carbon capture and storage to increase GHG sequestration capacity. The results of this study should hold under measures to achieve a 1.5-degree scenario as they involve an accelerated deployment of the technology modelled here. This scenario would be likely to result in positive employment growth as renewables and energy efficiency promote greater employment creation than fossil fuels. The development of carbon capture and storage would create additional employment opportunities, as noted by Wei, Patadia and Kammen (2010).

Several assumptions, common to the input–output methodology, should be considered when interpreting these results. While we extend conventional input–output methods by making scenarios on the basis of supply-and-use tables that factor in structural and demand-side changes, according to IEA scenarios, we do not attempt to model behavioural responses on the basis of these changes. For one, the models presented here assume that relative prices and the world trade structure remain constant. While this allows us to identify the linkages and sectors most affected by the energy transition, it results in models that ignore adjustment effects. This means that our results assume that firms and sectors are able to absorb changes in demand immediately and that there are no factor substitutions induced by price changes. It also means that rises in productivity in emerging industries are not taken into account. If, for example, technological change drives down the cost of a specific green technology and the technology matures, the labour requirements could diminish, reducing the employment benefits of adopting this technology. Nor do we consider the potential for completely new technologies or products that currently do not exist. Other adjustment effects which were not considered relate to the ability of labour to adjust rapidly and meet changes in demand. However, owing to rigidities in the labour market, such as skills mismatch, adjustment to changing demand for goods and services may take longer, reducing the employment-creation potential of the scenarios proposed. As such, our results may overestimate the overall effect of employment changes, although the overall sectoral reallocation would still occur if these factors were considered.[24] In addition, we measure job reallocation between the 163 industries in EXIOBASE 3. This ignores movement between the sub-industries in that classification or between firms within each sector; it also ignores movement within firms that may result from the transition towards energy sustainability.

Though effects may be small, the changes in the energy sector and the related employment changes will not happen by themselves. Achieving an employment-friendly structural change in the energy system requires comprehensive policy action by government, employers, workers, industry, research and the public (ILO, 2015). Pricing alone will not be sufficient to achieve the 2-degree goal in an employment-friendly manner. Industrial policy is required to facilitate the development of emerging industries. Investment in systems of education and training is necessary to build the required human capital and skills across the entire labour market to meet changes in demand (idem, 2018; Strietska-Ilina, 2017). Standards and codes for buildings or vehicles, especially relevant in the context of energy efficiency, should address non-price barriers. Policy design needs to be long-term, predictable, holistic and based on social dialogue in order to take account of interdependencies among energy systems and technologies, human capital and social restructuring. Social dialogue is essential in tackling barriers resulting from the political economy and vested or perceived interests. Social protection and active labour market measures should also be developed during the transition in order to protect displaced workers and facilitate their employment in emerging sectors. Financing is key to providing the additional US$ 40 trillion in capital required to move from the business-as-usual path to the 2-degree path. This will unlock US$ 115 trillion

[24] As an alternative to input–output (IO) models, computable general equilibrium (CGE) models are also used to estimate employment impacts of technological change. Perrier and Quirion (2018) estimate the employment impact of investing in low-carbon sectors in France using both IO and CGE models. They find that both IO and CGE models predict positive employment effects of investing in solar panels and household energy efficiency.

in fuel cost savings. Options to finance this extra investment include financing through development banks, loan guarantees or publicly backed green bonds to cover investment risks.

In short, making deep cuts to carbon emissions will require a significant structural change in the global economy. Renewable energy technologies must be scaled up at the expense of traditional fossil fuel-based technologies. Such changes will have an important effect on employment in certain industries and in certain regions. Our study has made an attempt to quantify the scale of this change across global supply chains. The overall economy-wide effect on employment between a business-as-usual scenario and a low-carbon scenario (in line with a 2-degree scenario) is estimated to be small and positive in most economies and regions. The positive effect on employment is driven in particular by an increase in jobs related to the manufactured capital of renewable energy technologies, and is visible through growth in employment in the construction, manufacturing and renewables sectors.

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Appendix

Table A1. Net employment change and excess job reallocation by country and region by 2030 under a 2-degree scenario

Economy or region	Percentage change (relative to 6-degree scenario)		Absolute change (thousand jobs)	
	Net employment change	Excess reallocation	Net employment change	Excess reallocation
Australia	0.37	0.02	65	4
Austria	0.48	0.09	25	5
Belgium	0.07	0.39	4	24
Brazil	0.78	0.26	877	295
Bulgaria	0.93	0.55	45	26
Canada	0.44	0.23	109	57
China	0.32	0.04	4 856	672
Croatia	0.25	0.05	5	1
Cyprus	0.48	0.13	3	1
Czech Republic	0.64	0.15	45	11
Denmark	0.31	0.15	11	5
Estonia	0.77	0.09	7	1
Finland	0.73	0.12	23	4
France	0.29	0.14	109	50
Germany	0.49	0.18	268	100
Greece	0.42	0.20	20	10
Hungary	0.60	0.15	36	9
India	0.12	0.43	1 326	4 944
Indonesia	0.86	0.05	2 139	123
Ireland	0.21	0.12	7	4
Italy	0.27	0.34	76	95
Japan	0.70	0.05	456	32
Korea, Republic of	0.43	0.06	175	26
Latvia	0.35	0.08	6	1
Lithuania	0.24	0.74	5	15
Luxembourg	0.15	0.14	1	1
Malta	0.51	0.01	1	0
Mexico	0.25	0.26	193	198
Netherlands	0.17	0.36	17	36
Norway	0.28	0.23	11	9
Poland	0.57	0.33	138	79
Portugal	0.26	0.34	15	20
Romania	0.25	0.43	46	78
Russian Federation	0.01	0.62	11	500
Slovakia	0.41	0.58	15	21
Slovenia	0.66	0.10	8	1
South Africa	0.63	0.14	112	25

(continued overleaf)

Table A1. Net employment change and excess job reallocation by country and region by 2030 under a 2-degree scenario *(concl.)*

Economy or region	Percentage change (relative to 6-degree scenario)		Absolute change (thousand jobs)	
	Net employment change	Excess reallocation	Net employment change	Excess reallocation
Spain	0.22	0.12	56	30
Sweden	0.19	0.05	12	3
Switzerland	0.25	0.13	14	7
Taiwan, China	0.91	0.08	140	13
Turkey	0.34	0.14	143	57
United Kingdom	0.32	0.10	140	43
United States	0.47	0.31	1 000	665
Rest-of-World – Africa	0.18	0.11	1 156	736
Rest-of-World – Asia and the Pacific	0.26	0.33	2 962	3 750
Rest-of-World – Europe	0.35	0.43	716	892
Rest-of-World – Latin America and the Caribbean	0.28	0.51	507	934
Rest-of-World – Middle East	–0.15	0.67	–103	453
World	**0.29**	**0.24**	**18 011**	**15 068**

Notes: Net job creation measured against the 6-degree scenario baseline. When expressed as a percentage, it is expressed as a share of 6-degree scenario total employment. Between-sector excess job reallocation is measured against the 6-degree scenario baseline, across the 163 industries in table A2 in the Appendix. When expressed as a percentage it is expressed as a share of 6-degree scenario total employment. World absolute net creation and reallocation are the sums of the economy- and region-specific creation and reallocation, respectively. World percentage figures are with respect to projected world employment in the 6-degree scenario.

Source: Authors' calculations based on EXIOBASE 3.

Table A2. EXIOBASE 3 industry aggregation

EXIOBASE industries	Aggregated industry
Cultivation of paddy rice	Agriculture
Cultivation of wheat	Agriculture
Cultivation of cereal grains n.e.c.	Agriculture
Cultivation of vegetables, fruit, nuts	Agriculture
Cultivation of oil seeds	Agriculture
Cultivation of sugar cane, sugar beet	Agriculture
Cultivation of plant-based fibres	Agriculture
Cultivation of crops n.e.c.	Agriculture
Cattle farming	Agriculture
Pig farming	Agriculture
Poultry farming	Agriculture
Meat animals n.e.c.	Agriculture
Animal products n.e.c.	Agriculture
Raw milk	Agriculture
Wool, silk-worm cocoons	Agriculture
Manure treatment (conventional), storage and land application	Agriculture
Manure treatment (biogas), storage and land application	Agriculture
Forestry, logging and related service activities	Agriculture
Fishing, operating of fish hatcheries and fish farms; service activities incidental to fishing	Agriculture
Mining of coal and lignite; extraction of peat	Mining
Extraction of crude petroleum and services related to crude oil extraction, excluding surveying	Mining
Extraction of natural gas and services related to natural gas extraction, excluding surveying	Mining
Extraction, liquefaction and regasification of other petroleum and gaseous materials	Mining
Mining of uranium and thorium ores	Mining
Mining of iron ores	Mining
Mining of copper ores and concentrates	Mining

(continued overleaf)

Table A2. EXIOBASE 3 industry aggregation *(cont.)*

EXIOBASE industries	Aggregated industry
Mining of nickel ores and concentrates	Mining
Mining of aluminium ores and concentrates	Mining
Mining of precious metal ores and concentrates	Mining
Mining of lead, zinc and tin ores and concentrates	Mining
Mining of other non-ferrous metal ores and concentrates	Mining
Quarrying of stone	Mining
Quarrying of sand and clay	Mining
Mining of chemical and fertilizer minerals, production of salt, other mining and quarrying n.e.c.	Mining
Processing of meat cattle	Manufacturing
Processing of meat pigs	Manufacturing
Processing of meat poultry	Manufacturing
Production of meat products n.e.c.	Manufacturing
Processing of vegetable oils and fats	Manufacturing
Processing of dairy products	Manufacturing
Processed rice	Manufacturing
Sugar refining	Manufacturing
Processing of food products n.e.c.	Manufacturing
Manufacture of beverages	Manufacturing
Manufacture of fish products	Manufacturing
Manufacture of tobacco products	Manufacturing
Manufacture of textiles	Manufacturing
Manufacture of wearing apparel; dressing and dyeing of fur	Manufacturing
Tanning and dressing of leather; manufacture of luggage, handbags, saddlery, harnesses and footwear	Manufacturing
Manufacture of wood and of products of wood and cork, except furniture; manufacture of articles of straw and plaiting materials	Manufacturing
Re-processing of secondary wood material into new wood material	Waste mgt. and rec.
Pulp	Manufacturing
Re-processing of secondary paper into new pulp	Waste mgt. and rec.

Table A2. EXIOBASE 3 industry aggregation *(cont.)*

EXIOBASE industries	Aggregated industry
Paper	Manufacturing
Publishing, printing and reproduction of recorded media	Manufacturing
Manufacture of coke oven products	Manufacturing
Petroleum refinery	Manufacturing
Processing of nuclear fuel	Manufacturing
Plastics, basic	Manufacturing
Re-processing of secondary plastic into new plastic	Waste mgt. and rec.
N-fertilizer	Manufacturing
P- and other fertilizers	Manufacturing
Chemicals n.e.c.	Manufacturing
Manufacture of rubber and plastic products	Manufacturing
Manufacture of glass and glass products	Manufacturing
Re-processing of secondary glass into new glass	Waste mgt. and rec.
Manufacture of ceramic goods	Manufacturing
Manufacture of bricks, tiles and construction products, in baked clay	Manufacturing
Manufacture of cement, lime and plaster	Manufacturing
Re-processing of ash into clinker	Waste mgt. and rec.
Manufacture of other non-metallic mineral products n.e.c.	Manufacturing
Manufacture of basic iron and steel and of ferro-alloys and first products thereof	Manufacturing
Re-processing of secondary steel into new steel	Waste mgt. and rec.
Precious metals production	Manufacturing
Re-processing of secondary precious metals into new precious metals	Waste mgt. and rec.
Aluminium production	Manufacturing
Re-processing of secondary aluminium into new aluminium	Waste mgt. and rec.
Lead, zinc and tin production	Manufacturing
Re-processing of secondary lead into new lead, zinc and tin	Waste mgt. and rec.
Copper production	Manufacturing
Re-processing of secondary copper into new copper	Waste mgt. and rec.

(continued overleaf)

Table A2. EXIOBASE 3 industry aggregation *(cont.)*

EXIOBASE industries	Aggregated industry
Other non-ferrous metal production	Manufacturing
Re-processing of secondary other non-ferrous metals into new other non-ferrous metals	Waste mgt. and rec.
Casting of metals	Manufacturing
Manufacture of fabricated metal products, except machinery and equipment	Manufacturing
Manufacture of machinery and equipment n.e.c.	Manufacturing
Manufacture of office machinery and computers	Manufacturing
Manufacture of electrical machinery and apparatus n.e.c.	Manufacturing
Manufacture of radio, television and communication equipment and apparatus	Manufacturing
Manufacture of medical, precision and optical instruments, watches and clocks	Manufacturing
Manufacture of motor vehicles, trailers and semi-trailers	Manufacturing
Manufacture of other transport equipment	Manufacturing
Manufacture of furniture; manufacturing n.e.c.	Manufacturing
Recycling of waste and scrap	Waste mgt. and rec.
Recycling of bottles by direct reuse	Waste mgt. and rec.
Production of electricity by coal	Fossil and nuclear
Production of electricity by gas	Fossil and nuclear
Production of electricity by nuclear	Fossil and nuclear
Production of electricity by hydro	Renewables
Production of electricity by wind	Renewables
Production of electricity by petroleum and other oil derivatives	Fossil and nuclear
Production of electricity by biomass and waste	Renewables
Production of electricity by solar photovoltaic	Renewables
Production of electricity by solar thermal	Renewables
Production of electricity by tide, wave, ocean	Renewables
Production of electricity by geothermal	Renewables
Production of electricity n.e.c.	Renewables
Transmission of electricity	Utilities
Distribution and trade of electricity	Utilities

Table A2. EXIOBASE 3 industry aggregation *(cont.)*

EXIOBASE industries	Aggregated industry
Manufacture of gas; distribution of gaseous fuels through mains	Utilities
Steam and hot water supply	Utilities
Collection, purification and distribution of water	Utilities
Construction	Construction
Re-processing of secondary construction material into aggregates	Waste mgt. and rec.
Sale, maintenance, repair of motor vehicles, motor vehicle parts, motorcycles, motorcycle parts and accessories	Services
Retail sale of automotive fuel	Services
Wholesale trade and commission trade, except of motor vehicles and motorcycles	Services
Retail trade, except of motor vehicles and motorcycles; repair of personal and household goods	Services
Hotels and restaurants	Services
Transport via railways	Services
Other land transport	Services
Transport via pipelines	Services
Sea and coastal water transport	Services
Inland water transport	Services
Air transport	Services
Supporting and auxiliary transport activities; activities of travel agencies	Services
Post and telecommunications	Services
Financial intermediation, except insurance and pension funding	Services
Insurance and pension funding, except compulsory social security	Services
Activities auxiliary to financial intermediation	Services
Real estate activities	Services
Renting of machinery and equipment without operator and of personal and household goods	Services
Computer and related activities	Services
Research and development	Services
Other business activities	Services

(continued overleaf)

Table A2. EXIOBASE 3 industry aggregation *(concl.)*

EXIOBASE industries	Aggregated industry
Public administration and defence; compulsory social security	Services
Education	Services
Health and social work	Services
Incineration of waste: Food	Waste mgt. and rec.
Incineration of waste: Paper	Waste mgt. and rec.
Incineration of waste: Plastic	Waste mgt. and rec.
Incineration of waste: Metals and inert materials	Waste mgt. and rec.
Incineration of waste: Textiles	Waste mgt. and rec.
Incineration of waste: Wood	Waste mgt. and rec.
Incineration of waste: Oil/hazardous waste	Waste mgt. and rec.
Biogasification of food waste, incl. land application	Waste mgt. and rec.
Biogasification of paper, incl. land application	Waste mgt. and rec.
Biogasification of sewage sludge, incl. land application	Waste mgt. and rec.
Composting of food waste, incl. land application	Waste mgt. and rec.
Composting of paper and wood, incl. land application	Waste mgt. and rec.
Waste water treatment, food	Waste mgt. and rec.
Waste water treatment, other	Waste mgt. and rec.
Landfill of waste: Food	Waste mgt. and rec.
Landfill of waste: Paper	Waste mgt. and rec.
Landfill of waste: Plastic	Waste mgt. and rec.
Landfill of waste: Inert/metal/hazardous	Waste mgt. and rec.
Landfill of waste: Textiles	Waste mgt. and rec.
Landfill of waste: Wood	Waste mgt. and rec.
Activities of membership organizations n.e.c.	Services
Recreational, cultural and sporting activities	Services
Other service activities	Services
Private households with employed persons	Services
Extra-territorial organizations and bodies	Services

Note: n.e.c. = not elsewhere classified.
Source: EXIOBASE 3.