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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 to keep 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 flow-on impact to other sectors. Using scenarios based on a multi-regional input-output database, this paper explores the economy- 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.

## Introduction

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 surface average temperature and change in the climate system (IPCC, 2013, 2014a; Steffen, Broadgate, Deutsch, Gaffney, & Ludwig, 2015; Steffen, Richardson, et al., 2015). The Intergovernmental Panel on Climate Change highlights the many, mostly negative, effects of climate change on the environment, societies and the economy; the burden of these effects will fall mostly on vulnerable countries and population groups (ILO, 2018; IPCC, 2014a). 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 times to below 2 degrees Celsius by the end of the century (UNFCCC, 2015).

Action to limit climate change suffers from the fact that benefits are felt in the long term, but any perceived costs of mitigation are felt today. It also suffers from the fact that those responsible for inducing climate change are not the same as those burdened by its consequences (Stern, 2007). Indeed, real or perceived short-term costs in terms of GDP growth and employment may discourage the adoption of climate action, even if long term benefits accrue (Brekke & Johansson-Stenman, 2008).

Given the importance of employment in the political economy of climate change (Babiker & Eckaus, 2007), this paper addresses the employment implications of the 2-degree objective. Does taking globally coordinated action that would effectively limit global warming to 2 degrees Celsius create employment opportunities or job losses in the medium term? Will

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this transition entail a reallocation of employment across industries? Are economies ready to confront these structural changes? In analysing a scenario that achieves the 2-degree goal, this paper finds 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 highlighting the industries and economies that will experience job losses and reallocation, this paper highlights the specific areas for policy action to ensure that a transition to sustainability is also just.

The following section describes how climate action impacts employment across the whole of the global economy, noting that complementary policy changes areas are needed for climate action to be employment friendly. The paper then describes the data and methods to estimate the medium-term impact of climate action on employment. Results and conclusions are then discussed.

## The low carbon transition and employment

Current economies rely heavily on the emission of $CO_2$ and other greenhouse gases (GHG) to meet their energy and product demand (IPCC, 2013; Steffen, Broadgate, et al., 2015).[4] Despite a reduction in GHG intensity over the past 25 years (in 1990, 0.82 kgs of $CO_{2\text{-eq}}$ GHGs were emitted for each 2011 PPP dollar of GDP; in 2014 this had been reduced to 0.48) total GHG emissions grew, from 39 to 54 gigatons of $CO_{2\text{-eq}}$ over this period due to GDP growing faster than reductions in GHG intensity (IEA, 2016a; World Bank, 2018).[5] GHG emissions stand far above the Earth's capacity to sequester these gases, producing climate change (IPCC, 2013).

Reducing the carbon intensity of economic activity further so that overall emissions decrease is a fundamental element of a climate-friendly economy (IPCC, 2014b; Ward et al., 2016). As energy is one of the primary sources of GHG emissions (IPCC, 2014b), advancing a climate-friendly economy requires promoting energy efficiency, on the one hand, and advancing the share of energy sources that do not emit GHGs.[6] This is largely acknowledged in the Nationally Determined Contributions submitted by signatories to the Paris Agreement

[4] Energy demand is the major 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 important source of GHGs. Another important source of climate change is the reduction of the biosphere's ability to absorb greenhouse gas emissions, notably through land use change (IPCC, 2013).

[5] Carbon-dioxide ($CO_2$) is the largest contributor to greenhouse gases (GHG) which, in turn, are responsible for climate change. Other GHGs include methane, nitrous oxides and F-gases (HFCs, PFCs and SF6). For the purposes of simplicity, non-$CO_2$ GHGs are converted to a $CO_2$-equivalence ($CO_{2\text{-eq}}$) 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 are largely $CO_2$.

[6] A low carbon economy also requires the reduction of non-energy based GHGs, like those stemming 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 GHGs emitted. As more than 50 per cent of GHG emissions result from energy demands, a low carbon economy cannot take place without specific attention to the energy sector (IEA, 2015).

(IRENA, 2017; UNEP, 2017) and by different agencies providing advice with respect to measures specific to the energy sector (DDPP, 2015; IEA, 2015, 2017; IPCC, 2014b).

The International Energy Agency (2015) lays out a path in the adoption of renewable energy sources and the increase in energy efficiency to achieve the 2-degree goal.[7] The IEA's 2-degree path suggests, at the worldwide level and compared to a business-as-usual path that would lead to global warming of around 6 degrees Celsius, a 55 per cent reduction in electricity generated by coal, a 26 per cent reduction in electricity generated by natural gas and a 13 per cent reduction in electricity generated by oil. The 2-degree path also projects an increase in electricity generated by renewables like geothermal, wind, solar photovoltaic, nuclear and hydro (at 75, 75, 59, 46 and 16 per cent, respectively), among other sources. It also projects a reduction in total electricity generation of 9 per cent due to increases in energy efficiency. Table 1 outlines the expected difference in energy demand by energy source between the business-as-usual scenario and the IEA's scenario to achieve the 2-degree goal.

**Table 1 Changes in energy sources by 2030 to achieve the 2-degree scenario**

| | 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 buildings, 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.

A shift away from fossil fuels and towards renewables and energy efficiency will undoubtedly affect employment in the energy sector, as the amount of labour needed to obtain a similar output differs by energy source. Advancing towards energy sustainability will imply a reallocation of labour across energy sub-sectors and affect the total employment in the energy sector. Wei et al. (2010) find that the labour intensity of electricity generated by renewables is higher than that generated from fossil fuels. Solar

[7] In the Paris Agreement, countries pledge to follow their Nationally Determined Contributions (NDCs) to achieve the 2-degree goal. The analyses in this article focus on the IEA (2015) and its path to achieve the 2-degree goal. The analyses do not focus on the NDCs because there is still a gap between what can be achieved with the currently defined NDCs and the 2-degree goal (UNEP, 2017).

photovoltaic electricity, for example, requires 0.87 total person years for each GWh of electricity generated while electricity from coal or natural gas requires 0.11. This explains why the recent growth in the share of renewables is linked to an increase in employment in the electricity sector worldwide (Montt, Maitre, & Amo-Agyei, 2018).

Yet the effects of the adoption of renewables and the increase in energy efficiency implies a structural change that goes far beyond the energy sector itself, shifting demand for products and services throughout the economy (Bowen, Duff, & Fankhauser, 2016; Bowen & Kuralbayeva, 2015a). Indeed, the energy sector is tightly linked, by forward and backward linkages to many other industries. Changes in the energy sector – through changes in electricity generation, transport or construction – will necessarily touch other sectors as well. In the case of energy in the automotive sector, for example, electric vehicles entail very different value chains than internal combustion engine vehicles, altering forward- and backward-linked industries. Automotive vehicles change the final demand for oil products and shift consumer spending patterns as well (UBS Research & UBS Evidence Lab, 2017).

These indirect effects have employment implications. The electricity sector is one of the sectors with the highest employment multipliers in the economy (WEF & IHS CERA, 2012). In the United Kingdom in 2010, for example, for each job created in the electric power generation, transmission and distribution sector, 5.27 jobs are created in other sectors, ranking 4$^{th}$ amongst 127 economic sectors (the extraction of crude petroleum and natural gas and mining of metal ores has the highest employment multiplier, at 10.1) (Wild, 2014). In Scotland, in 2013, the employment multiplier of the electricity sector was 2.5, ranking fifth among 98 sectors analysed (Scottish Government, 2016). Garrett-Peltier (2017) shows that a spending increase of USD 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 support 7.72 jobs. (For other examples, see Cassar, 2015; OECD, 2010; Stehrer & 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 energy efficiency and renewables creates employment in the construction and renewables sector, but also in the manufacturing of electrical parts and in the mining of copper ores. The shift also reduces employment opportunities in fossil fuel-related sectors like coal mining, petroleum refinery and refuelling stations, for example (Fragkos & Paroussos, 2018; ILO, 2018; Mercure et al., 2018; New Climate Economy, 2018).

The net employment effects that result from changes in the energy sector to achieve the 2-degree goal points to the total number of jobs created. Though informative, it is a limited measure of the employment impact. It does not capture how jobs move from one industry to another (i.e. excess reallocation between industries) (Davis & Haltiwanger, 1992). For each economy, then, the total effect on employment (creation, destruction and reallocation) will depend on a) the extent to which the energy sector needs to shift towards renewables and more efficiency, b) the linkages between the energy sub-sectors affected and other industries, c) the labour intensity of the sectors that gain and lose activity and d) 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 important economic and employment changes. Whether they bring about employment creation, destruction and/or reallocation across industries, an economy requires solid institutions, adequate industrial policy, regulation and capabilities to achieve any such structural change and for it to be employment friendly (Salazar-Xirinanchs, Nubler & Kozul-Wright, 2014). Such institutions include effective governments, the reliable provision of public services, consistent and coherent policy formulation and the capacity to ensure law and order, among many others. They guide this structural transformation, setting the framework for local action (Acemoglu, Johnson, & Robinson, 2001; Lehtonen, 2004; Sokoloff & Engerman, 2000). In the specific case of employment, they help ensure that workers can satisfy the change in demand for employment that results from the structural transformation to sustainable economies (Bowen & Kuralbayeva, 2015b). They also help protect workers and firms in particular sectors or regions against any negative impact in terms of displacement and lower demand (ILO, 2018).

This paper explores the employment implications of following a 2-degree pathway for the energy sector. It takes into account all the ways in which a change in the energy sector will affect employment. The paper first answers the question of whether a 2-degree pathway creates or destroys jobs, on the aggregate in an economy compared to a business-as-usual scenario (i.e. net employment change). These effects are generally positive, but small and do not identify reallocation effects. The paper then shows that this excess reallocation between industries exists, but is also relatively small in comparison to yearly changes in the economy. To understand these small, yet generally positive effects, the paper then explores the labour intensity of the industries that grow and decline, finding that although important for the economy as a whole, the industries most affected generally employ a small number of workers. Though generally small, the effects are not ignorable. This is why the paper then links these employment changes to the broad characteristics of each economy, and to their institutional characteristics, to identify the characteristics that best predict employment gains or losses and identify economies' ability 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 create global, economy-wide scenarios of technology and demand change: one for a baseline (business-as-usual) and another for a 2-degree scenario that would achieve the 2-degree goal in the Paris Agreement. We perform a comparative analysis between the two scenarios to estimate the economy-level net employment creation and reallocation of jobs between industries. We explore the economy-level characteristics associated to those outcomes and analyse the institutional preparedness to adopt policies that advance the 2-degree objective and positive employment outcomes simultaneously.

The scenarios are built on EXIOBASE, a multiregional input–output (MRIO) system that reports the interlinkages between final consumption, the flow of intermediate and final goods and factor inputs into production. 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. EXIOBASE has 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.[8] Amongst other environmental and socio-economic extensions, EXIOBASE reports total employment, female employment, employment by skill level, vulnerable employment, and total GHG emissions for each sector in each economy.[9] Tukker et al. (2013), Wood et al. (2014) and Stadler et al. (2018) provide more information on EXIOBASE and its potential uses. A detailed description of EXIOBASE's labour accounts can be found in the online supporting information from Stadler et al. (2018). One of the major advantages of EXIOBASE for the analysis of the 2-degree objective is its highly detailed electricity and resource sector (11 different electricity generators modelled, and delineation of all major primary fuels).

EXIOBASE v3 provides a time-series of data from 1995 and up to 2016 with progressively less data available (more recent data is "now-casted", see Stadler et al. (2018) ). We use 2014 as the base-year for the scenarios undertaken in this work, which is the last year with detailed trade data incorporated. We project the 2014 dataset to 2030 combining the International Monetary Fund (IMF) GDP projections to 2022 with the International Energy Agency (IEA) regional growth projections to 2030 (IEA, 2016b; IMF, 2017). 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 v3 (Wiebe, Bjelle, Többen & Wood, 2018).

## *Identifying indirect effects*

Changes in the energy sector affect a variety of industries, given the strong economic linkages between the energy sector and the rest of the economy. For energy and all other sectors, MRIO tables record the flow of intermediate goods and services in the world economy and, with that, they map the inter-industry linkages in the global economy. Analyses based on MRIO systems capture how changes in one specific industry (e.g. the electricity generation sector) produce direct and indirect output and employment effects. These are employment effects in the electricity generation industry itself (i.e. direct effects) as well as changes in other upstream or downstream industries (e.g. 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 unit of production of final goods of industry $j$ is calculated as

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

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

[8] Table A2 in the Appendix provides a list of the 163 industries in EXIOBASE. The table also lists how each of these industries is aggregated into broader sectors: agriculture, mining, manufacturing, fossil fuels and nuclear, renewables, utilities, construction, services and waste management. Except when noted explicitly, the analyses of this paper generally draw on the 163-industry classification.

[9] EXIOBASE is available through the project's website: www.exiobase.eu .

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 the production structure, i.e. technological change (Koning, Huppes, Deetman, & Tukker, 2016; Wiebe, 2016). The 2-degree scenario affects many different industries and parts of the economy. It requires investment into new technologies, which have to be produced, and it changes final and intermediate demand when these technologies are used. An increasing share of electric cars, for example, requires first a change in the input structure of the automobile industry (more batteries and related parts, fewer combustion engines). Then, when the cars are used, the demand for electricity increases, while the demand for diesel and gasoline decrease. 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 consistently model technological change in a forward-looking multiregional input–output model, and to this end, differentiates between five types of changes regarding parts of the input–output system (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.

In Wiebe (2018), these changes are explained using the example of increasing electricity production through wind turbines. This first change requires an increased investment in wind power. It entails a change in the structure of gross fixed capital formation as investments in wind power drive more money into wind power-related business services, machinery and equipment and away from other industries (IOT change 1).

This then induces a change in the machinery and equipment industry because, on the one hand, more wind turbines are produced, increasing the share of these products within the machinery and equipment industry, and, on the other hand, other machinery and equipment industry products decline in their share of output within the machinery and equipment industry (IOT change 2). In economies with large machinery and equipment industries, the overall industry structure changes very little with the higher production of wind turbines. In economies with smaller machinery and equipment industries, as would be the case of Denmark, for example, this can have a large impact on the industry input structure. These changes in the electricity technology-producing industry are modelled using data on input coefficient vectors for renewable electricity technologies from Lehr et al. (2011).

Once there is more wind power capacity installed, the inputs used for electricity generation in the country changes (IOT change 3). Electricity generation requires fewer non-wind power sources (e.g. coal), reducing the demand for electricity generated from these non-wind power sources and their related inputs, but would increase the demand for wind power-related services and maintenance. Further, the $CO_2$ emission intensity of electricity production goes down and the employment intensity of electricity production goes up, as wind power requires comparatively more labour per unit of output than fossil-fuel based electricity (Wei et al. 2010) (IOT change 4). Finally, directly and indirectly value added and industry output change because of changing final and intermediate demand patterns (IOT change 5).

This strategy applies to input-output tables 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, Bruckner, Giljum & Lutz, 2012) used in Wiebe (2018), the OECD's Inter-Country Input-Output Tables (ICIO) (Wiebe & Yamano, 2016) or the World Input-Output Database (WIOD) (Timmer et al., 2014). In EXIOBASE (Stadler et al., 2018), which is used for the analysis here, the electricity industry is disaggregated into 11 different technologies. For the scenarios we have therefore changed the demand (final and intermediate) for the different types of electricity according to the shares assumed in the IEA 6DS and 2DS scenarios. This induces changes in the inputs needed for the overall electricity sector, and the emissions intensity of the average electricity generation (IOT change 3 and 4), as well as inducing 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 import shares at the product level 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.

Results from MRIO scenarios, as presented here, are first-order impacts, devoid of the effects of assumptions about substitution elasticities, utility and profit maximization, price equilibrium, etc. Some key assumptions, common to all MRIO scenario exercises, include:

- Prices are not endogenised, that is, 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 macro-economic price or growth effects, are not taken into account.[10]
- Market shares and bilateral trade shares remain constant.

Though these assumptions may be considered limitations, the scenario approach employed here allows for more detail (both regional, sectoral and technological) to be maintained in the modelling than other approaches that would incorporate these issues in the model. [11]

### *The scenarios*

The International Energy Agency (2015) developed a 2-degree scenario (2DS) for the decarbonisation of the world economy and a 6-degree, business-as-usual, scenario (6DS). The 2DS would sufficiently reduce greenhouse gas emissions to limit global warming to 2

[10] Gillingham et al. (2013) argue that rebound effects are generally small.
[11] The data used by Wiebe, Bjelle, Többen and Wood (2018) and used in this paper is available at https://doi.org/10.5281/zenodo.1342557 . The code used by Wiebe, Bjelle, Többen and Wood (2018) which we adapt is available at https://github.com/kswiebe/FEMRIOv1_EXIOfuturesIEAETP/ .

degrees Celsius above the pre-industrial average. The 6DS is a largely a continuation of current trends.

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

The 2DS 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. In terms of concentration of GHG gases, this scenario limits GHGs to 450 parts per million in the atmosphere. One way to achieve the 2°C target or this concentration, is to reduce global $CO_2$ emissions from the energy sector. $CO_2$ 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 observed in 2012 to 27 gigatons in 2030 and 14 gigatons in 2050.

The 2DS 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, 39 per cent fewer $CO_2$ emissions by 2030 that those 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. The transition entails, on the other, increased efficiency across the other three sectors. In this regard, by 2030, total energy demand for industry, transport and buildings decrease 20, 29 and 14 per cent, respectively, when compared to the business-as-usual 6DS.[12]

The 6DS is largely an extension of current trends in emissions and fossil fuel use for primary energy demand. No major technological change is modelled as it is assumed that there are no new policies undertaken to limit global warming.

The broad directives of the 2-degree path and its comparison to the business-as-usual 6-degree path by 2030 is illustrated in Table 1 above for OECD and non-OECD economies.

As described by the IEA (2015), to achieve the 2-degree goal, a total of USD 358.8 trillion capital investments are required by 2050. This is USD 40 trillion more than is required in the business-as-usual/6-degree scenario (318.4 trillion USD). The following average annual capital investments are needed up to 2050 to achieve the 2-degree goal:

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

[12] By 2050 the 2DS entails 74 per cent fewer $CO_2$ emissions than the business-as-usual scenario. By 2050 it entails 30, 44 and 28 per cent fewer energy demand in the industry, transport and buildings sectors.

Importantly, in the IEA's 2-degree scenario, accumulated fuel cost savings are estimated to be around USD 115 trillion by 2050, more than offsetting the additional capital investments of USD 40 trillion. The major portion of the additional investments required and savings achieved are in non-OECD member economies, reflecting strong demand growth in emerging economies.

We use the four energy technology system transformations of 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 shifts towards the four modelled low-carbon industries and that the additional required USD 40 trillion investments in the 2-degree scenario are financed through the expected savings of USD 115 trillion. Aggregate projected GDP growth in the 2-degree and the 6-degree scenario converge by 2030 while at industry and economy level growth rates follow the scenario specifications. We then project the MRIO up to 2030 for the 2-degree scenario.[13]

These two scenarios change very few components in the system. The scenarios should therefore be analysed relative to each other and not in absolute terms 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 the business-as-usual 6-degree scenario with no technological change.

## *Net employment creation and between-sector excess reallocation*

The model provides the total employment projected in 2030 in the 2DS and the 6DS for each of the 163 sectors in EXIOBASE, for each of the 44 economies and 5 rest-of-the-world regions. For each economy, we estimate the net employment change between the two scenarios. We also estimate the excess reallocation associated to the 2-degree scenario, following Davis and Haltiwanger (1992). While net employment change measures the total number of additional (fewer) jobs that result in the 2DS compared with the 6DS, excess reallocation measures the jobs that moved from one of the 163 industries in EXIOBASE to another. To better understand the magnitude of the change, we also discuss the labour intensities of the industries most touched by the 2-degree scenario.

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

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

[13] This paper draws on the energy demand and efficiency targets and investment packages laid out the by the IEA (2015). Infinite scenarios exist to achieve the 2-degree goal by 2050, including those that assume lower or zero economic growth in developed countries (e.g. Victor, 2012). Scenarios proposed by the Deep Decarbonization Pathways Project (DDPP) largely follow the one used in this paper in that they promote the use of renewables and energy efficiency. They are robust to different specifications and investment pathways (DDPP, 2014, 2015).

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The net employment creation does not capture all the employment changes involved in the 2DS compared to the 6DS. Theoretically, a net employment change of zero is compatible with a large change in employment, insofar even if, on the aggregate, no net jobs were created or destroyed, jobs moved from one industry to another.[14] This movement of jobs across industries is the excess job reallocation (Davis & Haltiwanger, 1992). It can be calculated as the difference between total net employment change (Equation 2) and the total movement of jobs between the 163 industries in EXIOBASE, that is, the reallocation that is more than the minimum compatible with a given net change:[15]

$$excess_c = \frac{\sum_{i \in S} |e_{c,i}^{2DS} - e_{c,i}^{6DS}|}{\sum_{i \in S} e_{c,i}^{6DS}} - |netemp_c| \qquad (3)$$

In order to explore the mechanisms underlying the magnitude of changes in a given sector/country, we discuss the labour intensity of a given sector relative to the country average. The model assumes fixed labour intensities $\alpha_{c,i}$, i.e. a fixed quantity of employment per unit of added-value in all scenarios: $e_{c,i}^{S} = \alpha_{c,i} y_{c,i}^{S}$, where $y_{c,i}^{S}$ is the added-value of country $c$ industry $i$. Therefore, one can compute a measure of relative labour intensity, for a given country-sector pair, which is given by

$$\breve{\alpha}_{c,i} = \frac{e_{c,i}^{DScenario} / \sum_{i \in S} e_{c,i}^{6DS}}{y_{c,i}^{DScenario} / \sum_{i \in S} y_{c,i}^{6DS}} \quad DScenario \in (2DS, 6DS) \qquad (4)$$

To explore whether certain economies are more prone to experience higher (or lower) net job creation and between-sector excess reallocation, we link these employment outcomes to characteristics of the economy. Such aggregate characteristics, extracted from the World Bank's World Development Indicators, include GDP per capita and the economy's reliance on natural resource rents (expressed as a percentage of GDP), patents per capita, as well as initial employment shares for each (aggregate) economic sector. As the energy transition touches some specific industries directly and indirectly, this would allow to check 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 to check whether economies' development status, natural resource rent share or employment structure predict the level of job creation or between-sector excess reallocation, allowing to identify is certain economies face structural disadvantages with respect to the energy transition.

Finally, we also explore economies' institutional preparedness for the changes to the level and distribution of employment across sectors. Institutions play a determinant role in economic development (see, for example, Acemoglu et al., 2001), to facilitate a structural transformation (Salazar-Xirinanchs et al., 2014) and enhance the response to climate change (World Bank, 2008). The World Bank's Worldwide Government Indicators capture

[14] Another and component of employment shifts consist of within sector reallocation, as jobs move from one firm to another within the same industrial sector. Though relevant, within-sector reallocation is beyond the scope of the present study as the bigger share of the impact of moving towards the 2DS and away from the 6DS involves a change between industries (Bowen, Duff, & Fankhauser, 2016).

[15] 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 experience an employment loss in a sector *i*, while country 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.

institutional characteristics on the basis of firms and household surveys, as well as expert assessments from NGOs, multilateral organizations and other organizations (Kaufmann, Kraay, & Mastruzzi, 2011). We focus on Government effectiveness, an indicator that captures the perceived effectiveness of the civil service and public services, as well as the quality of policies and their implementation and the credibility of governments' commitment to these policies. Effective governance, as an element of an economy's institutional capacity, may be important in the context of a structural transformation, to meet the demand for new skills (in the case of employment creation), for protection and opportunities for mobility to displaced workers (in case of employment loss), as well as for the effective reorganization of the economy (in case of reallocation of jobs across industries).

## Results

Adopting the measures projected by the International Energy Agency (2015) to limit global warming to 2 degrees Celsius (2DS) by the end of the century will result, according to our estimation, in approximately 0.3 per cent more net jobs around the world in 2030 when compared to the business-as-usual scenario (6DS). Compared to global annual changes in employment, this net employment change is small. The annual change in employment in the average economy across the world was 1.5 per cent per year over the 2005-2017 period. Over the same period, 25 per cent of all observed national employment changes over this period had an average annual employment growth of over 2.6 per cent.[16] In the 2DS no economy has an expected net job creation that exceeds 1 per cent compared to the 6DS. Overall, the net job creation that could be expected by the 2DS is equivalent 18 million new net jobs.

Figure 1 shows these percentage differences at the economy level. Of the 44 individual economies analysed, all see net job creation. This net job creation, in percentage terms, is greatest in Bulgaria, Taiwan and Indonesia (all around 0.9 per cent). The economies that are projected to experience comparatively high net job creation under the 2DS are generally economies that still have a high need to increase the share of renewables in their energy mix and improve energy efficiency to advance sustainability in the sector. Indonesia and Taiwan, for example, still rely heavily on fossil fuels to meet their energy demand. Some of them are also economies with an industrial structure that will contribute to satisfy the demand for new goods related to energy efficiency and renewables (e.g. Taiwan and Bulgaria).

Jobs-wise, and very much in relation to the size of these economies, net job creation between the scenarios is about 4.9 million in China, 2.1 million in Indonesia, 1.3 million in India and 1 million in the United States.

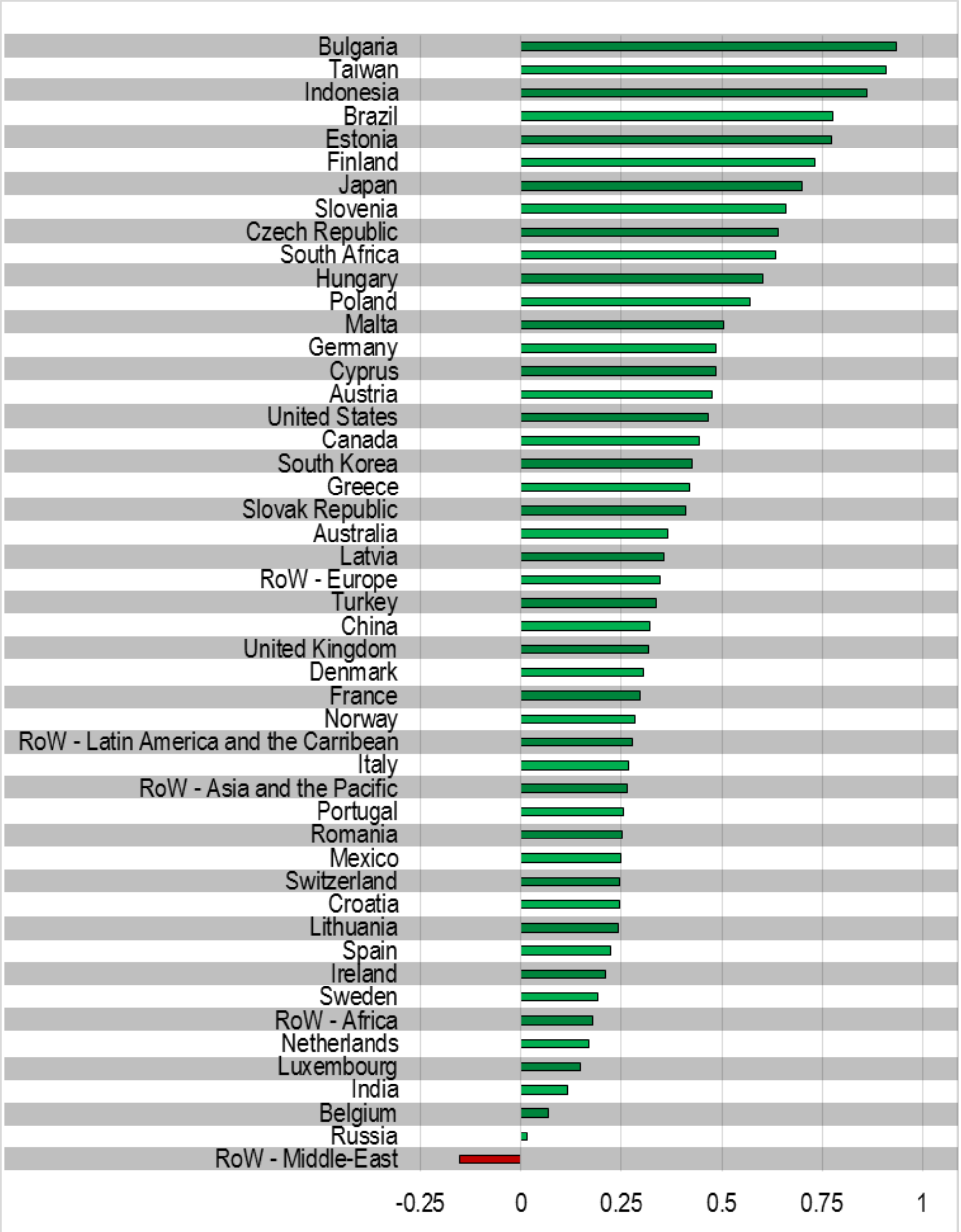
Of the 5 rest-of-the-world regions, the Middle East may experience net job losses and Sub-Saharan Africa[17] is expected to experience a small net job creation, which may not be different than any change at all. These regions may not benefit from the transition because

[16] Annual employment growth estimates calculated from ILOStat.
[17] The rest-of-the-world Africa region does not include South Africa, which is included as an individual country in the analyses. It does not include Northern African countries that are included in the rest-of-the-world Middle East region.

they have a heavy economic reliance on fossil fuels and because of the fact that 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'/regions' industries as basis for the projection. For example, Sub-Saharan African economies with a very small or non-existent renewable energy manufacturing industry will grow from a very small base and, in absolute terms, grow only marginally in low carbon technologies and output. This is because we assume no industrial policies which would alter trade structure or tap into Sub-Saharan Africa's significant renewable energy resource export potential. Indeed, the continent has the potential to source an additional 10 terawatts of solar energy, 1,300 gigawatts of wind power and 1 gigawatts of geothermal potential (APG, 2015).

**Figure 1 Net employment change in the 2-degree scenario, 2030, percentage**




Note: Bars express the difference in employment between the 2-degree scenario and the 6-degree scenario, as share of 6-degree scenario total employment. For example, adopting the 2-degree scenario will bring, in Japan, 1.25 per cent more employment than the business-as-usual scenario. Bars in red signal net employment losses. Absolute numbers associated to these changes are available in Table A1 in the Appendix.
Source: Authors' calculation based on EXIOBASE v3.

At the industry level, as already noted by the ILO (2018), the 2-degree scenario increases demand for employment in industries like construction, the manufacturing of electrical machinery, electricity generation from renewables and the mining of copper ores. Of a total of 163 industries analysed, 35 industries may experience employment growth of 100,000 or more, only 8 may experience losses of this magnitude. Job destruction is concentrated in a few industries that include, most notably, petroleum refining, the extraction of crude petroleum, production of electricity by 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. The between-sector reallocation measures the movement of jobs from one industry to another within economies. With EXIOBASE, between-sector reallocation measures the movement of employment between each economy's 163 industries. It does not measure employment reallocation within each of these industries, nor within firms.

In total, across the 163 industries and economies, between-sector excess 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.[18] Although the Russian Federation is expected to experience a relatively minor, if any, effect 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 reallocation rate for Indonesia is smaller 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 reallocation ratio is weakly and negatively associated with net employment change, partly by construction ($\rho$=-0.35), as one can see in comparing Figures 1 and 2. A notable exception is the Middle East, which is projected to experience both a large loss and a large reallocation highlighting the significant employment challenges that the region may face as a result of the transition to energy sustainability.

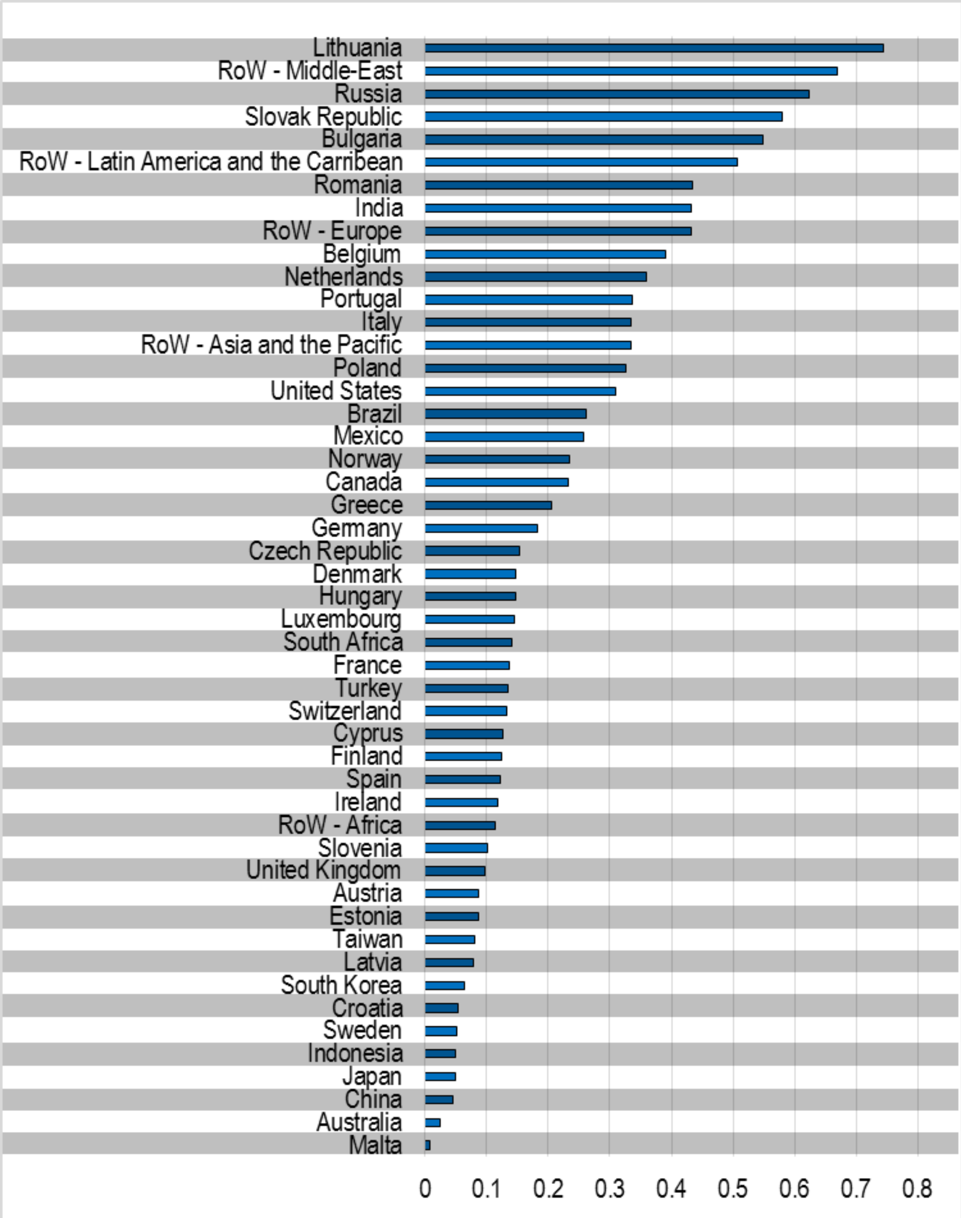
To put these numbers in perspective, between-sector excess reallocation generally represents to 2 to 4 per cent of an economy's total employment per year (Cahuc, Carcillo, & Zylberberg, 2014).[19] From this perspective, the largest estimates of excess reallocation ratios estimated here only correspond to fractions of typical annual shifts. Like total net employment creation, between-sector 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 reallocation, the implementation of policies to reach the Paris Agreement's 2°C objective is projected to have a generally positive and relatively small effect on employment.

**Figure 2 Excess between-sector reallocation in the 2-degree, 2030, percentage**

[18] These figures are computed as the sum of the projected between-sector reallocation rate of observed economies and regions; expressed as a percentage, the sum is divided by the total projected employment in the 6-degree scenario. Excess reallocation is calculated from the 163-industry classification shown in Table A1.

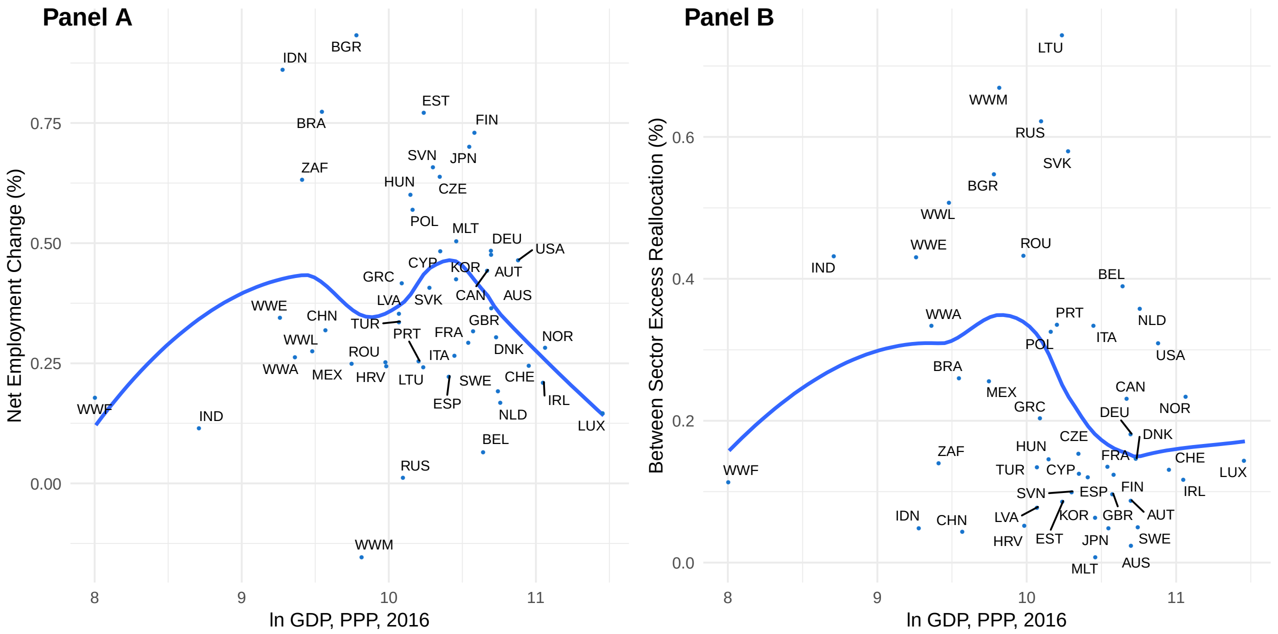
[19] Total excess reallocation ratios (between and within sectors) are typically between 15 and 25 per cent (Cahuc, Carcillo, & Zylberberg, 2014). Between-sector reallocation at an industrial sector breakdown used in this study, typically represents 15 per cent of total excess reallocation (Davis & Haltiwanger,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




Note: Bars express the reallocation of employment across the 163 industries in Table A2 between the 2-degree scenario and the 6-degree scenario, as a share of 6-degree scenario total employment. For example, adopting the 2-degree scenario will mean that, in the United States, a total of 0.58 per cent of employment will shift from one industry to another. Absolute numbers associated to these changes are available in Table A1 in the Appendix.
Source: Authors' calculation based on EXIOBASE v3

Net employment change and excess reallocation show a weak, at best, relationship with (log) GDP per capita, signalling that the employment opportunities and employment changes associated to a 2-degree scenario are not confined to developing or developed economies. Figure 3 shows the relationship between (log) GDP per capita in 2016 PPP and expected net employment change (Panel A) and excess reallocation (Panel B). The correlation between (log) GDP per capita and the net employment change, in percentage, is insignificant ($\rho$=-0.04). Indeed, economies with similar GDP capita are expected to experience different net employment changes. This is the case, for example, of Lithuania and Estonia; both have similar GDP per capita levels, and yet the estimated net creation is roughly 0.25 in Lithuania but over 0.75 per cent in Estonia. Similarly, 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 reallocation: the expected between-sector reallocation is unrelated to (log) GDP. The correlation between (log) GDP per capita and excess reallocation is also statistically insignificant ($\rho$ = -0.22) (Figure 3, Panel B). This means that economies with similar GDP per capita levels can experience very different excess reallocation by 2030 as a result of the transition to energy sustainability (e.g. Belgium and Sweden) or that economies that will experience similar levels of reallocation between industries can have different GDP per capita levels (e.g. France and South Africa).

**Figure 3 Net employment change and excess reallocation in the 2-degree scenario vs. GDP per capita**




Notes: GDP per capita for 2016, in 2011 USD 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 reallocation measured with the 163-industry classification is non-significant at -0.22. Economy names as per their ISO 3166-1 alpha-3 letter code. WWA, WWF, WWL and WWM represent rest-of-Asia, rest-of-Africa, rest-of-Latin America and the Caribbean, and the Middle East, respectively. The fitted curve is obtained through locally weighed scatterplot smoothing.
Sources: Authors' calculation based on EXIOBASE v3 and World Development Indicators.

Table A1 in the appendix summarises the net job creation and excess reallocation results for each economy in EXIOBASE and calculated on the basis of the 163-industry classification in Table A2. It shows the percentage change expected for each of these dimensions of employment change in a scenario of energy transition as well as the absolute expected change.

**Table 2 Net employment creation, excess reallocation and national economic and structural characteristics**

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

Notes: Data for 2016 except for the shares of employment by sector which corresponds to 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. Dependent variables are expressed as a percentage of BAO total employment. * $p < .1$, ** $p < .05$, *** $p < .01$ .
Source: Authors' calculation based on EXIOBASE v3 and World Development Indicators.

Table 2 explores the linkage between the expected employment changes and each economy's characteristics. As economies and regions that will experience high levels of reallocation or relatively less favourable employment effects tend to have important fossil fuel-related sectors (e.g. the Middle East, the Russian Federation), the results in the table explore whether net employment creation and between-sector excess reallocation are related to other attributes, typically linked to economies' employment structure, their 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 and between-sector excess reallocation. 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 one 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 level of patents (one measure of innovation) will tend to experience lower reallocation between industries. This is probably due to the fact that more innovative economies, those that have a higher relative number of patents, have more employment in the sectors less likely to be affected by the energy transition (Model 6).[20]

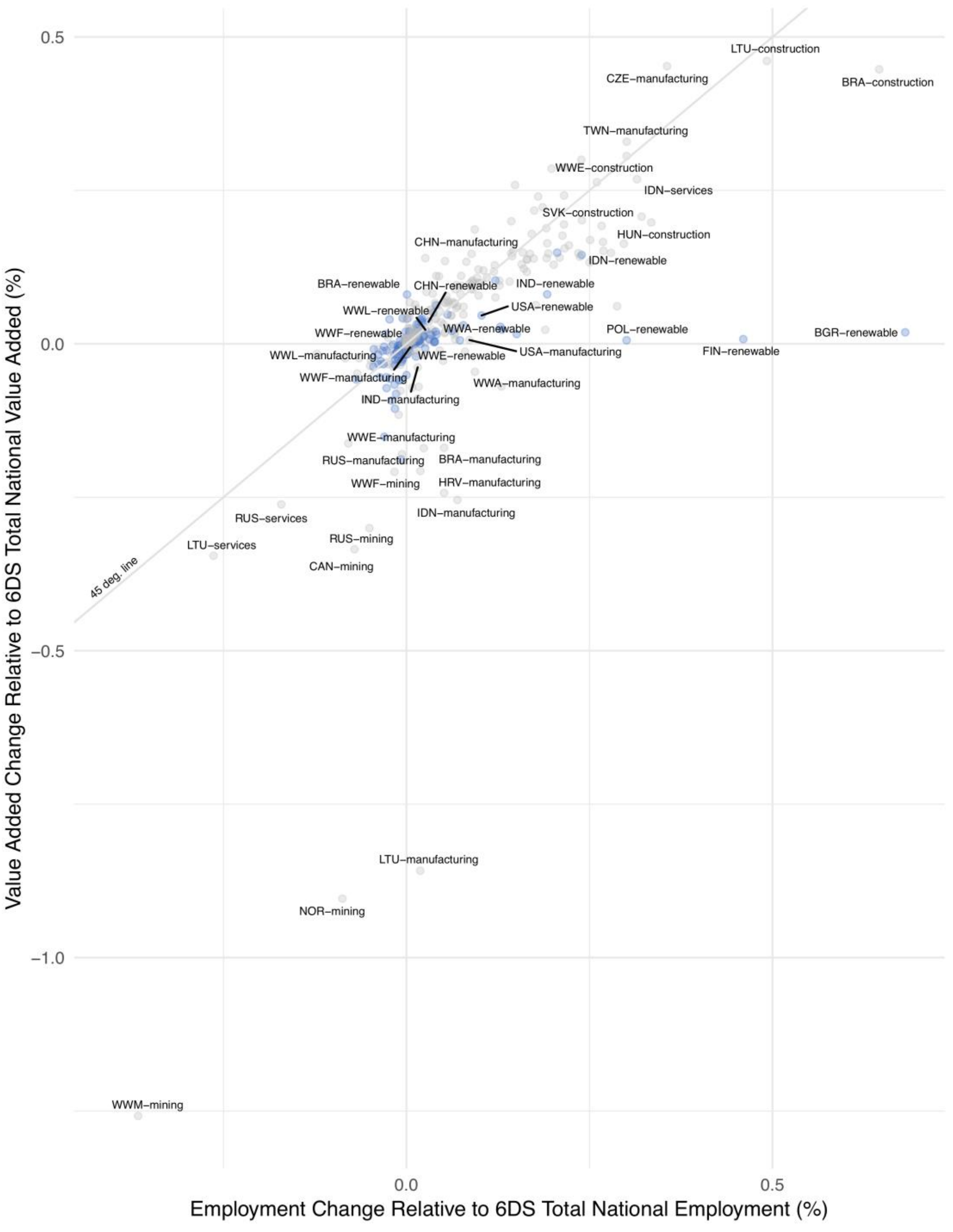
Overall, the results shown above highlight the weak impact of a transition to a 2-degree scenario on employment, despite the fact that the transition involves a structural transformation in the energy sector. Figure 4 shows the change in employment and the change in value-added, by industry and economy. For convenience, the 163 sectors have been aggregated into nine broad categories: agriculture, construction, manufacturing, mining, services, waste management, and three sectors directly related to energy generation and distribution: renewables, fossil/nuclear and utilities (all three represented in blue in the graph) (Table A2 in the Appendix provides the detail of the aggregation). Added value and employment changes are normalized by the economy total: $(x_{c,i}^{2DS} - x_{c,i}^{6DS}) / \sum_{i \in S} x_{c,i}^{6DS}$ for $x_{c,i}$ being the added-value 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 2DS compared to the 6DS, is below the 45° line. This means that the increase in employment in the sector (relative to total national employment, horizontal axis) is larger than the increase in value added (relative to total national value added, 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 2DS.

First, the transformation in the energy sector (renewable, fossil/nuclear as well as utilities) has a small net employment effect because these sectors are relatively small in the context of any economy's GDP. For example, the increase in renewables modelled in the scenario that would achieve the 2-degree scenario contributes to only 0.03 per cent of value-added at the global scale.

Second, sectors most touched by the transition have a relatively low labour intensity. The value-added effect of the transition is negative and largest for mining, but the overall effect is small because the sector exhibits low labour intensity. Take for example the sector-economy pair that is the most affected of all: the mining sector in the Middle East. As a result of the transition, it is projected to reduce its value added by about 1.3 per cent of GDP, but only by around 0.4 per cent of total employment.

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

**Figure 4 Change in Added-Value and Net Employment**

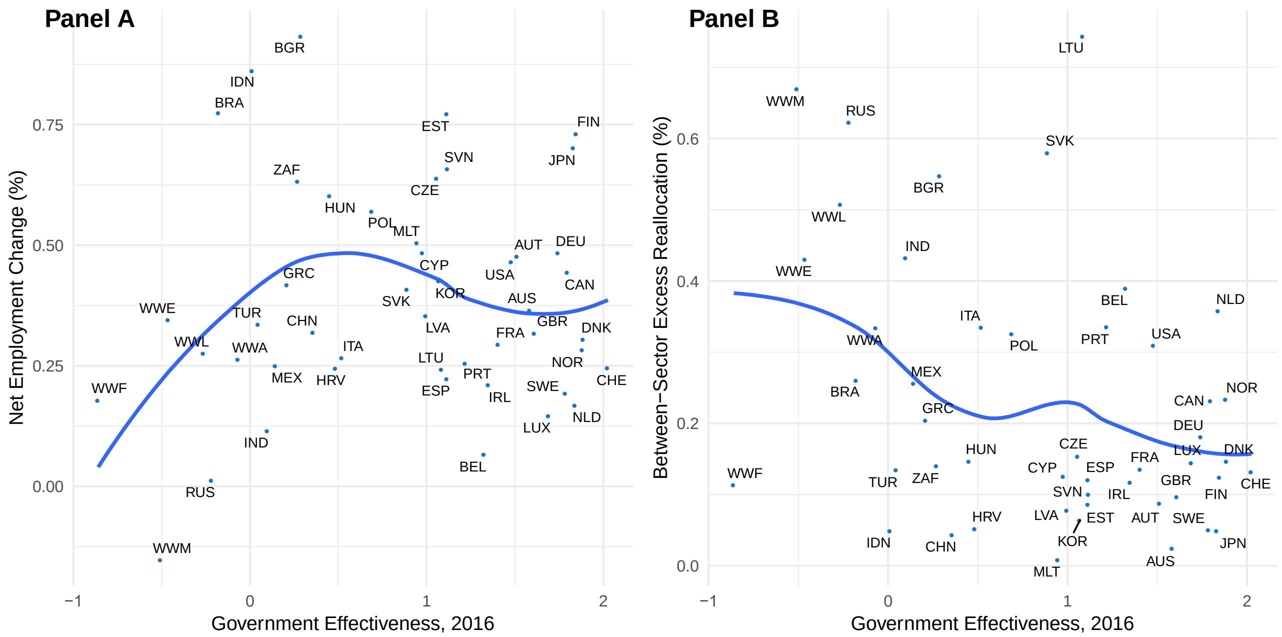



Notes: Each dot represents an aggregate sector-economy pair. Table A2 provides more detail on the industry aggregation. Blue dots represent energy related sectors (renewable, non-renewable, utilities). To facilitate exposure only selected economy-sector pairs are labelled. Economy names as per their ISO 3166-1 alpha-3 letter code. WWA, WWF, WWL and WWM represent rest-of-Asia, rest-of-Africa, rest-of-Latin America and the Caribbean and the Middle East, respectively. The position of each point relative to the 45 degree line helps identify the relative labour intensity of the economy-sector pair: a line drawn from the point to the origin may be steeper than the 45 degree line, in this case, the economy-sector pair has a relatively low labour intensity because relative value added is expected to grow at a faster pace than relative employment.
Sources: Authors' calculation based on EXIOBASE v3.

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 larger employment change than the former.

Despite the fact that overall employment effects are expected to be small, they are non-ignorable. They tend to be concentrated in specific industries and regions. They require the capacity for an economy to adapt, reskill, move their labour to meet new demand and protect workers and communities who 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 like government effectiveness may facilitate an economy’s smooth transition. Strong institutions can enable the rapid implementation of policies aimed at the economy’s adaptation to new environmental regulation, such as reskilling or other active labour market programmes, which support an effective reallocation of workers across industries. Strong institutions may also create better linkages between skill development programmes and changing labour demand, allowing skills development to react faster and more efficiently to changing labour demand. They may also allow for a faster and effective deployment of social protection schemes.

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




Note: Between-sector excess reallocation measures with the 163-industry classification. Economy names as per their ISO 3166-1 alpha-3 letter code. WWA, WWF, WWL and WWM represent rest-of-Asia, rest-of-Africa, rest-of-Latin America and the Caribbean and the Middle East, respectively. The fitted curve is obtained through locally weighed scatterplot smoothing. Source: Authors’ calculation based on EXIOBASE v3 and Worldwide Governance Indicators.

Government effectiveness measures the institutional capacity of an economy.[21] Figure 5 links government effectiveness with the net employment creation and excess reallocation

[21] Government effectives 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 the

results from Figures 1 and 2. Of interest are economies and regions that will experience relatively high employment changes with relatively weak institutions. These are economies that may be particularly ill-prepared to adapt to the transition and realise the potential it can bring. Ill-prepared economies may not be able to protect workers and firms who may lose out from the transition; these economies may be incapable of meeting the basic demands to advance a just transition. Such is 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). Effective government may facilitate the movement of workers across industries in the Russian Federation.

## Discussion

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 (ILO, 2018). Mitigating climate change through limiting global warming to 2 degrees Celsius is a key step towards environmental sustainability. It requires, among other measures, taking concerted action in the energy sector to limit its greenhouse gas emissions. This involves a shift away from carbon-emitting fossil fuel-based energy sources through the adoption of 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 degrees Celsius will impact other sectors in the economy. Given these linkages, employment throughout the economy is also likely to be affected by a shift in the energy sector. In exploring the International Energy Agency's (2015) proposed path to limit global warming to 2 degrees Celsius, this paper shows that on the aggregate, employment changes, as measured by net employment change and excess reallocation between industries, do exist, they tend to be positive but generally small in magnitude. They are consistent with those identifying the reallocation of labour associated to the shift from fossil fuel based energy sources to renewables (e.g. Fragkos & Paroussos, 2018). In contrast to those that focus solely on the move away from fossil fuels and that identify negative effects in certain economies (e.g. Louie & 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 (which is also observed in Garrett-Peltier, 2017).

Employment effects are concentrated in specific industries. Job destruction is concentrated mostly in industries related to fossil fuels (e.g. coal mining, petroleum refinery, 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, as well as the generation of electricity from renewable sources, the manufacturing of electrical parts and machinery and the mining for copper ores. Skills

credibility of the government's commitment to such policies" (World Bank, 2017). The index includes indicators such as infrastructure disruption, political instability, quality of bureaucracy, quality of primary education, satisfaction with public services, civil service integrity, and trust in government, among others.

development will be crucial to meet the increased demand for labour in these sectors. As job losses and job creation will not necessarily occur in the same geographical region, mobility incentives might be needed to achieve a friction-less reallocation between industries.

Though economies with a higher dependence of natural resources on their GDP are more likely to experience negative employment outcomes and those with a higher share of employment in manufacturing are likely to experience a higher net job creation, general economic and structural attributes do not accurately predict the extent and nature of the employment change. This suggests that there are no structural factors constraining or predetermining economies' outcomes in the transition. Institutional readiness and economies' ability to guide this transition, absorb the negative employment effects and create the conditions for the potential for job creation to realise could become a constraint in advancing an employment friendly energy transition. This is particularly relevant for developing economies that may have resource constraints to develop this institutional capacity.

These results show that, in the political economy of climate change mitigation through energy transformation, employment is not an obstacle to advance climate action. If any, the effects are positive for most economies and they are small. This is because although the change may be important in economic terms, it affects industries that have relatively low labour intensities the most. Whatever change is expected, it can be made smoother if the appropriate policy to transition to energy sustainability is taken gradually over to 2030.

Several assumptions, common to the input-output methodology, should be considered when interpreting these results. Whilst we extend conventional input-output methods by making scenarios on supply-use tables that factor in structural and demand-side changes according to IEA scenarios, we do not attempt to model behavioural responses to these changes. For one, the models presented here assume that relative prices and the world trade structure remain constant. Though this allows to identify the linkages and sectors most affected by the energy transition, it results in models that ignore adjustment effects. This means that results assume that firms and sectors are able to immediately absorb changes in demand and that there are no price or factor substitutions that result from changes in prices. It also means that increases 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 this technological adoption. The potential for completely new technologies or products that currently do not exist are also not considered. Other adjustment effects not considered relate to the ability of labour to adjust rapidly and meet changes in demand. Yet owing to skills mismatch, for example, and other rigidities in the labour market, it may take longer to adjust to changing demand for goods and services, reducing the employment creation potential of the scenarios proposed. As such, it may be that our results over-estimate the overall effect of employment changes if these factors are considered, but the overall sectoral reallocation would still occur. In addition, we measure reallocation between the 163 industries in EXIOBASE. 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 transitioning towards energy sustainability.

Though effects may be small, the changes in the energy sector and the related employment changes will not happen by themselves. To achieve an employment-friendly structural change to the energy system, comprehensive policy action is required from 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 into systems of education and training are necessary to build the required human capital and skills across the entire labour market to meet changes in demand (ILO, 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, based on social dialogue and holistic to address interdependencies among energy systems and technologies, human capital and social restructuring. Social dialogue is essential to address 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 to protect displaced workers and facilitate their employment in emerging sectors.  Financing is key to provide the additional required USD 40 trillion in capital to move from the business-as-usual path to the 2-degree path. This will unlock USD 115 trillion in fuel cost savings. Options to finance this extra investment for climate action include financing through development banks, loan guarantees or publicly backed green bonds to cover investment risks.

# Conclusion

Achieving 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 at quantifying 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 2degree warming) is estimated to be small and positive in most economies and regions. The positive effect on employment is driven in particular by increased jobs related to the manufactured capital of renewable energy technologies, and is visible through increases in employment in the construction, manufacturing and renewables sectors.

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# Appendix

## Table A1 Net employment creation and excess reallocation by country and region under a 2-degree path scenario, 2030

| | Percentage change (relative to 6-degree scenario) | | Absolute change (thousand jobs) | |
|---|---|---|---|---|
| Economy or region | 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 |
| 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 |
| Russia | 0.01 | 0.62 | 11 | 500 |
| Slovak Republic | 0.41 | 0.58 | 15 | 21 |
| Slovenia | 0.66 | 0.10 | 8 | 1 |
| South Africa | 0.63 | 0.14 | 112 | 25 |
| South Korea | 0.43 | 0.06 | 175 | 26 |
| Spain | 0.22 | 0.12 | 56 | 30 |
| Sweden | 0.19 | 0.05 | 12 | 3 |
| Switzerland | 0.25 | 0.13 | 14 | 7 |
| Taiwan | 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 |

**Table A1 (Continued)**

| Economy or region | Percentage change (relative to 6-degree scenario) | | Absolute change (thousand jobs) | |
|---|---|---|---|---|
| | Net employment change | Excess reallocation | Net employment change | Excess reallocation |
| RoW - Africa | 0.18 | 0.11 | 1,156 | 736 |
| RoW - Asia and the Pacific | 0.26 | 0.33 | 2,962 | 3,750 |
| RoW - Europe | 0.35 | 0.43 | 716 | 892 |
| RoW - Latin America & the Car. | 0.28 | 0.51 | 507 | 934 |
| RoW - Middle East | -0.15 | 0.67 | -103 | 453 |
| **World** | **0.29** | **0.24** | **18,011** | **15,068** |

Note: Net job creation express the difference in employment between the 2-degree scenario and the 6-degree scenario. When expressed as a percentage, it is expressed as share of 6-degree scenario total employment. For example, adopting the 2-degree scenario will bring, in Japan, 0.70 per cent more employment than the business-as-usual scenario. Excess reallocation expresses the movement of employment in each economy across the 163 sectors in Table A2 between the 2-degree scenario and the 6-degree scenario. When expressed as percentage it is expressed as a share of 6-degree scenario total employment. For example, adopting the 2-degree scenario will mean that, in the United States, a total of 0.47 per cent of employment will shift from one industry to another. World absolute net creation and reallocation are the sums of the economy-specific creation and reallocation, respectively. World percentage figures are with respect to projected world employment in the 6-degree scenario.
Source: Authors’ calculation based on EXIOBASE v3.

## Table A2 EXIOBASE industry aggregation

| EXIOBASE industries | Aggregated industry |
|---|---|
| Cultivation of paddy rice | Agriculture |
| Cultivation of wheat | Agriculture |
| Cultivation of cereal grains nec | Agriculture |
| Cultivation of vegetables, fruit, nuts | Agriculture |
| Cultivation of oil seeds | Agriculture |
| Cultivation of sugar cane, sugar beet | Agriculture |
| Cultivation of plant-based fibers | Agriculture |
| Cultivation of crops nec | Agriculture |
| Cattle farming | Agriculture |
| Pig farming | Agriculture |
| Poultry farming | Agriculture |
| Meat animals nec | Agriculture |
| Animal products nec | 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 |
| 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 nec | Mining |
| Processing of meat cattle | Manufacturing |
| Processing of meat pigs | Manufacturing |
| Processing of meat poultry | Manufacturing |
| Production of meat products nec | Manufacturing |
| Processing of vegetable oils and fats | Manufacturing |
| Processing of dairy products | Manufacturing |
| Processed rice | Manufacturing |
| Sugar refining | Manufacturing |
| Processing of food products nec | 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 (Continued)**

| 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 nec | 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 nec | 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. |
| 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 nec | Manufacturing |
| Manufacture of office machinery and computers | Manufacturing |
| Manufacture of electrical machinery and apparatus nec | 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 nec | 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 nec | Renewables |
| Transmission of electricity | Utilities |

**Table A2 (Continued)**

| EXIOBASE industries | Aggregated industry |
|---|---|
| Distribution and trade of electricity | Utilities |
| Manufacture of gas; distribution of gaseous fuels through mains | Fossil and nuclear |
| 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 |
| 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 nec | Services |
| Recreational, cultural and sporting activities | Services |
| Other service activities | Services |
| Private households with employed persons | Services |
| Extra-territorial organizations and bodies | Services |

Source: EXIOBASE v3.