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An input-output approach

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Abstract

The employment impacts of the transition to a post-carbon economy are gaining increasing attention. The post-carbon transition implies fundamental changes in the economy followed by significant changes in the structure of labour demand. Industries with the highest carbon footprint are of utmost importance because of the large expected changes in supply chain structures forced by decarbonisation. The power industry is a crucial component of the transition since its decarbonisation can also help other sectors (such as transportation) switch to cleaner energy fuels. Renewable energy sources are promising technologies that could significantly help foster transition in the energy sector and to provide energy with almost zero greenhouse gas emissions. Restructuring away from fossil fuels will bring about associated job losses in non-renewable energy sectors together with job gains in the renewable energy ones. Building energy infrastructure with a significantly higher share of renewables will also require significant capital investments in new facilities, possibly further fostering employment. Understanding the overall net effects on employment (i.e. job gains vs. job losses) would help inform transition policies in order to design policies guided not only by environment and climate but also by social considerations. To estimate the net effects on employment related to the increasing share of renewable energy, we develop a forward-looking multi-regional input-output model that takes into account the labour demand associated with capital investments in renewable energy infrastructure, separately from operation and maintenance. Modelling capital formation separately allows for a more precise assessment of the changes in labour demand needed to deal with the transition and can better inform related adaptation policies. The modelling consists of gradually replacing the production of electricity from non-renewable energy sources with production from renewables by comparing the effects of two scenarios in five-year intervals until 2050. The model focuses on changes in the European Union (EU) plus the United Kingdom (UK) and shows the net effects on the number of jobs by skill level (low-, medium- and high-skilled) and gender, by industry group and by country.

Keywords: employment, electricity sector, input-output analysis, renewable energy transition

Executive summary

Changes in employment due to technological shifts driven by the need to transform our energy system (and, in particular, the electricity sector) to a post-carbon one are of interest to many studies. However, only a limited number of them work with projections or provide detailed country- and sector-level effects with a breakdown by skill level and by capital formation vs. operation and maintenance. We believe it is useful to distinguish these categories in order to obtain a more nuanced picture of labour demand during different phases of the transition since this enables an early response to future labour demand with appropriate measures related to employment, retraining, education and vocational training. This helps to address the persistent or potentially exacerbated imbalances and inequalities on the labour market and to steer the post-carbon transformation according to the principles of just transition.

Guided by such objectives, we develop a forward-looking multi-regional input-output model for the EU27+UK area with a detailed capital formation module. The model allows us to track the employment changes induced by transition in the electricity sector: 1) by operation and maintenance vs. capital formation; 2) by domestic employment effects vs. the spill-over abroad; 3) by skill level and gender; 4) in 165 economic sectors; 5) by 13 electricity sources; and 6) in 28 countries. We compare the employment effects of the Stanford WWS Scenario with 100 per cent renewable energy (Jacobson et al. 2017; Jacobson et al. 2019) with the baseline trajectory defined in the EU 2016 Reference Scenario (Capros et al. 2016) in five-year intervals over the assumed transition period of 2015-2050.

The results show a growth in labour demand as the share of renewable energy sources increases. In a 100 per cent renewable energy scenario, the electricity sector would see total labour demand in the period up to 2050 which is approximately twice as high as the reference scenario. However, the employment created by capital investments would take place only on a temporary basis, signalling a boom in labour demand during the first phase of the transition (approximately until 2030) followed by a decline that continues up to 2050. The overall employment effects by the end of the assumed transition period thus depend to a large extent on the direct (within electricity sectors themselves) and indirect (upstream) effects of the operation and maintenance of the 13 modelled electricity sources. Since renewables have, in general, higher labour intensity, the 100 per cent renewable scenario would result in an increased need for labour compared to the base year (2015) after the transition is accomplished.

Detailed breakdown by different categories further indicates that: 1) renewable energy sources generally require more high- and medium-skilled labour and are equally as, or even more, male-dominated than the electricity sector in 2015; 2) even if no targeted policies were implemented in terms of changing production supply chains, a shift to 100 per cent renewable energy would primarily create employment domestically (i.e. within the EU27+UK) rather than leading to spill-over effects in other regions of the world; 3) industries that are heavily involved in the process of capital formation (such as construction or the manufacture of machinery and equipment n.e.c.) will drive most of the job growth in the first phase of the transition.

1. Introduction

A 1.5°C global average temperature rise compared to preindustrial levels is seen as the breaking point above which the impacts of climate change on the economy, human health, ecosystems and resources will be disastrous (Hoegh-Guldberg et al. 2019). Transforming the electricity sector[1] by the expansion of renewable energy sources (RES) in order to cut global greenhouse gas (GHG) emissions is a critical (albeit not sufficient) component of the transition to a post-carbon economy. In line with the 2050 GHG emission targets, renewable energy sources have the potential to provide energy with almost zero greenhouse gas emissions. The contributions of wind and solar photovoltaics are seen as particularly promising (e.g. EIA 2018). At the same time, adaptive policies required to reach global climate targets, based on low-carbon technological solutions replacing GHG emissions-intensive industrial activities, will be very likely to have large implications for the organisation of the economy and society in general. This will result in a change in infrastructure, production and consumption patterns, and in the associated allocation of jobs.

Many roadmaps to a low-carbon or post-carbon economy (the terms are often used interchangeably but we use the latter to indicate a carbon neutral economy), have been formulated recently which track the expected changes in employment (e.g. Bernardo and D'Alessandro 2016; Böhringer et al. 2013; Fragkos and Paroussos 2018). The interest in employment is logical since the transition requires a contraction of carbon-intensive production and its replacement by carbon neutral technologies. This would be likely to result in major reallocations of the labour force as well as changes in the demand for labour in general. Such a shift may therefore also raise concerns for policy-makers related to the impacts of the transition on employers and employees (Geels et al. 2016). Studies on the employment effects of an increased share of production being taken by renewable energy tend to be optimistic and show a positive net impact (e.g. Blanco and Rodrigues 2009; Montt et al. 2018); for a meta-analysis see Stavropoulos and Burger 2020). In contrast, some (but generally fewer) studies – for example Almutairi et al. 2018 – estimate job losses related to the deployment of renewable (and nuclear) energy. The overall job effects of a large-scale deployment of renewable energy sources, in terms of their magnitude and temporal distribution as well as the impacts on different groups within society, thus remain an open question.

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[1] Note that we use the terms 'sector' and 'industry' interchangeably.

The distributional impacts are assumed to influence the societal as well as the political acceptance of transition (Garrett-Peltier 2017). If one segment of society is affected more strongly by transition, this may compromise (or trigger) its support. Hence, transition has to be seen not only as a technological and infrastructural problem but also as a socio-economic issue with explicit considerations towards various aspects of social justice (Geels et al. 2017; Jenkins et al. 2018). These considerations are often framed as 'just transition' (Goddard and Farrelly 2018; Jasanoff 2018; McCauley and Heffron 2018). Understanding the possibilities in terms of the expected allocation of the labour force and the required skills and specialisations (and, accordingly, education and vocational training) can provide valuable information for transition policies and, therefore, minimise the unfavourable impacts on society in terms of (un)employment on the one hand and the lack of an available and adequately skilled workforce on the other. For example, increased demand for high-skilled labour because of the highly specialised production associated with renewable energy sources can signify an increased need for education in related fields in order that the process of transformation is not compromised (Lucas et al. 2018). A comprehensive overview of the existing approaches to estimating the job creation potential of various renewable energy sources and their associated skill requirements is provided by Sooriyaarachchi et al. (2015) while a somewhat more detailed discussion of approaching skill shortages can also be found in Zekaria and Chitchyan (2019).

Our study reacts to this need for informed policy choices in order to formulate sectoral transitions guided by post-carbon objectives. We outline the expected employment impacts of the transition of the electricity industry by different skill levels, using 100 per cent renewables as suggested in a scenario by Jacobson et al. (2017) and Jacobson et al. (2019)[2] (hereafter the 'Stanford WWS[3] Scenario'), comparing these to the more moderate, 'baseline' trajectory defined in the EU 2016 Reference Scenario (Capros et al. 2016). We apply a forward-looking multi-regional input-output (MRIO) model capturing the assumed evolution of the employment effects over the transition period in five-year intervals with a base year of 2015 and a target year of 2050. We calculate net employment effects in terms of jobs (employed persons) for EU27 countries and the United Kingdom (hereafter EU27+UK) distinguishing a range of dimensions: 1) operation and maintenance vs. capital formation; 2) EU27+UK vs. spill-over to other world regions (i.e. the employment effects triggered by expenditure on renewables in the EU27+UK and abroad); 3) skill levels and gender; 4) sector; 5) different electricity sources; and 6) country.

Distinguishing between direct, indirect and induced jobs is common in classifying the types of employment change linked to changes in an economy analysed through the input-output approach (Miller and Blair 2009). It is an approach which is also widely used in studies dealing with renewable energy

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[2] An updated version has been available since 2019, expanding the scope of the scenario from 139 to 143 countries.

[3] WWS stands for wind, water and solar energy.

transition (IRENA 2017; Lambert and Silva 2012; Ortega et al. 2015). The direct effects refer to changes in electricity generation itself (for example, a decreasing number of employees in electricity production by coal, replaced by an increasing number of employees in electricity production from solar photovoltaics, wind, etc.). The indirect effects occur through the supply chains (i.e. the inputs from other sectors necessary to maintain electricity production). Induced jobs are created indirectly through the operation of the economic structure and associated supply chains in other sectors through changes in spending and do not directly support production, operation and maintenance in renewable energy sectors (Fragkos and Paroussos 2018: 936).

Our study focuses on direct and indirect employment changes since its forward-looking character makes estimations of the induced effects uncertain, being dependent on many other (non-modelled) factors. We further distinguish between domestic (in the analysed countries) and foreign (abroad) employment effects, capturing international trade linkages in the global economy. The employment effects are calculated in detailed country-level results to highlight and illustrate the most important insights. Our model does not, however, make any statement about which sectors will absorb changes in electricity output in any of the scenarios. We therefore track no structural changes in the economy besides those driven by changes in electricity production (the so-called ‘upstream’).

To obtain a more detailed representation of the transition process, we separate the employment effects of capital investments from the employment associated with operation and maintenance (hereafter O&M). Capital investments (or ‘gross fixed capital formation’ in input-output terminology, hereafter GFCF) are the expenditure needed to build new electricity infrastructure and facilities (manufacturing, construction and installation). The purpose of dealing with capital investments separately is to track the specific changes in employment related to the gradual replacement of the non-renewable electricity infrastructure with a renewable one during the different phases of the transition. This is because the GFCF-dominant phase of the transition might affect completely different industries in terms of labour demand and would, in this instance, also require different skills.

As primary data source we use (and make minor adaptations in) EXIOBASE 3.6 (Stadler et al. 2018) – a multi-regional global input-output database with detailed sectoral disaggregation and, crucially, detailed electricity sectors. Such a level of detail enables us to see the effects of replacing production technologies (the energy sources used in the production of electricity) in a transparent way since each production technology acts as a separate industry. This allows us to model changes in demand and calculate their employment effects[4] according to the shifts in each source’s share of electricity production. The report is organised as follows: in Section 2 we provide the broader context

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[4] This approach can also be used for assessing other effects such as GHG emissions, land-use, etc.

of the renewable energy and jobs topic by summarising the results and recommendations to date. In Section 3 we present the methodology and data used. First, we discuss the data used in the analysis and second, we explain the use of an input-output framework to analyse employment changes and describe the input-output model. Section 4 presents the results and Section 5 discusses the main results and their implications. Section 6 summarizes and concludes.

2. Literature review – employment effects of renewable energy

Substantial interest has recently been directed to the employment effects of the renewable energy transition on various scales ranging from municipalities, regions and countries to supranational entities such as the EU or to the global level (Köhler et al. 2019). Renewable energy is usually considered as potentially reducing unemployment while promoting economic performance (Fragkos and Paroussos 2018; Garrett-Peltier 2017). Wind and solar energy are especially assumed to have positive effects on job creation (Bernardo and D'Alessandro 2016; Blanco and Rodrigues 2009). The topic of 'green jobs', i.e. jobs created by the transition to renewable energy and other low-carbon technologies, has dominated many studies (see the overview by Deschenes 2015). The renewable energy sector has already been rising in terms of labour demand for quite some time. Recent numbers show that renewable energy industries created 11.5 million jobs in 2019 (IRENA 2020: 5). The solar photovoltaic (PV) industry is in the lead (with 3.75 million direct and indirect jobs globally in 2019) followed by bioenergy (3.58 million) and wind energy (1.17 million) (IRENA 2020). How these numbers compare to potential job losses in non-renewable energy industries and what implications this would have for the economy is unsurprisingly of significant interest.

There is a rather abundant amount of studies from numerous European countries and regions: Austria (Steininger and Voraberger, 2003); Catalonia (Rodríguez-Huerta et al., 2017); Czechia (Dvořák et al., 2017); Germany (Böhringer et al., 2013; Jenniches, 2018; Lehr et al., 2012, 2008); Spain (Caldés et al., 2009; Llera et al., 2013; Moreno and López, 2008); Greece (Markaki et al., 2013; Tourkolias and Mirasgedis, 2011); Croatia (Keček et al., 2019); Ireland (Dalton and Lewis, 2011; Kamidelivand et al., 2018); Italy (Dell'Anna, 2021); the Netherlands (Bulavskaya and Reynès, 2018); Poland (Böhringer and Rutherford, 2013; Wasiuta, 2018); Portugal (Oliveira et al., 2013); Switzerland (Füllemann et al., 2020); and the United Kingdom (Allan and Ross, 2019). For our purposes, however, we discuss in detail only those studies which are focused on the EU as a whole, possibly also including a country-level breakdown.

2.1 Employment effects of the renewable energy transition at EU level

2.1.1 Ex post studies

Markandya et al. (2016) use a multi-regional input-output model to analyse the job impacts of renewable energy between 1995-2009, finding a net total gain of 530 000 jobs (Markandya et al. 2016: 1345). Two-thirds of the overall effect is initiated domestically while the rest represents spill-over effects abroad from the demand. No fewer than 21 out of 27 EU member states see a positive total effect on employment (Markandya et al. 2016: 1345). In four eastern European countries the change in employment represents at least 0.8 per cent of total employment in 2009: Slovakia (1.6 per cent); Latvia (1.5 per cent); Hungary (1.4 per cent); and Poland (0.8 per cent). In contrast the changes in western European countries do not exceed 0.5 per cent with the largest 'winners' being Belgium, Austria and the Netherlands, gaining 0.5 per cent, 0.4 per cent and 0.4 per cent respectively (Markandya et al. 2016: 1346). At industry level, the main beneficiaries are: renting of machinery and other business activities (159 000 jobs); electricity and gas supply (64 000 jobs); construction (44 000 jobs); other community, social and personal services (41 000 jobs); and inland transport (38 000 jobs). The losing sectors are: mining and quarrying (-28 000 jobs); public administration and defence, and compulsory social security (-10 000 jobs); and coke, refined petroleum and nuclear fuel (-3000 jobs) (Markandya et al. 2016: 1346).

Ortega et al. (2015), also within an input-output framework, track existing employment changes related to the deployment of wind and solar PV energy. The estimated net effect is 548 019 jobs created in the EU28 from 2008 to 2012 (Ortega et al. 2015: 946). Most of the jobs are created during the manufacturing phase (56 per cent) followed by installation (27 per cent) and then operation and maintenance processes (17 per cent) (Ortega et al. 2015: 946). At country level, the main growth occurs in Germany (accounting for 38.9 per cent of the total rise in employment) followed by Denmark (11.8 per cent), Italy (11.5 per cent), Spain (9.5 per cent) and the United Kingdom (5.7 per cent) (Ortega et al. 2015: 946). Direct employment accounts for a majority of the share of the rise in employment (53 per cent of the total), with solar PV being relatively less important than wind energy.

2.1.2 Ex ante studies

Fragkos and Paroussos (2018), using both a direct employment factor approach (to assess the impacts on direct employment in energy sectors) and a computable general equilibrium (CGE) one (to analyse the impact on total employment across the economy), estimate that the renewable energy transition has a positive impact on jobs given the higher labour intensity (jobs per output in either monetary or physical terms) of RES compared to non-renewables. The results assume an increase of jobs in the electricity sector from 1.4 million in 2015 to 1.9 million in 2050 in the reference scenario and by 900 000 in the more ambitious scenario (in terms of renewable energy deployment) (Fragkos and Paroussos 2018: 942). The overall net effect of RES on employment in the energy sector is estimated to be 200 000 additional jobs compared to the reference scenario by 2050 (Fragkos and Paroussos 2018: 942). In comparison to the reference scenario, the main job gains by 2050 would be in the electricity sector (+471 000 full-time equivalent – hereafter FTE – jobs across the EU), the construction sector (+655 000) and in the agricultural sector (+277 000), the latter by way of biofuels. The main losers would be the non-renewable energy sectors (-323 000), other energy intensive industries (-779 000) and services (-154 000). In total, the net effect would be approximately 672 000 extra jobs by 2030, but a drop of 192 000 jobs in the decade to 2040 plus an additional 147 000 in the following decade to 2050 (Fragkos and Paroussos 2018: 943). The authors attribute the drop after 2030 to the end of construction-related jobs which is further compensated after 2040 by new required investments.

The authors of the Stanford WWS Scenario (Jacobson et al. 2017; Jacobson et al. 2019) also provide estimates for the direct, indirect and induced job effects per unit of energy output related to the generation, transmission and storage of electricity, heating, cooling and hydrogen production using a basic input-output model (Billman and Keyser 2013), comparing the effects to a business as usual (BAU) scenario. The calculation takes into account FTE positions related to both the construction and the operation and maintenance phases. In terms of net employment change, the authors estimate that the WWS scenario sees net gains by 2050 of 28.65 million long-term (permanent) FTE jobs for the 143 countries compared to the BAU scenario. Note that due to differences in scope (heating, cooling and hydrogen production added to electricity generation), the results are not fully comparable to the results of our analysis.

For a further overview of *ex ante* analyses (with special regard to wind and solar PV deployment), we refer to the summary by Ortega et al. (2020: 3) comparing six roadmaps, each projecting changes in employment under different scenarios – and with different models – until 2030 or later (Cambridge Econometrics 2013; Duscha et al. 2016; EWEA 2012; Ragwitz et al. 2009; SolarPower Europe 2015; Teske et al. 2015). With the exception of the SNP-35 and QUO-35 scenarios of Duscha et al. (2014: 106) by 2050, all the analyses listed in Ortega et al. (2020) estimate job growth due to the increased deployment of RES (and note that, by 2030, the results of this roadmap also indicate job gains).

2.2 Distributional employment effects

Studies which focus explicitly on the distributional employment effects (i.e. in terms of skill level and gender, as in our analysis) are still relatively scarce even though the effects on various existing inequalities are crucial in avoiding potentially negative social outcomes (Markkanen and Anger-Kraavi 2019). Allan and Ross (2019), Blanco and Rodrigues (2009) and Cai et al. (2014)

are among the few examples. Cai et al. focus on China and male domination in renewable energy sector jobs, comparing it to male dominance in extractive sectors as well as in machinery manufacture (Cai et al. 2014: 1160). Similarly, according to Blanco and Rodrigues (2009: 2856), wind energy is a predominantly male business in line with male dominance in associated engineering and construction sectors. Gender balance matters because, as previous research shows, it can further influence the general perspective on energy use, energy policy, environmental consciousness and social awareness (Clancy and Roehr 2003; Ryan 2014). Nevertheless, gender balance is also not a fixed constant but rather a changing factor reflecting many policy choices as well as cultural shifts.

Analysing the distributional effects by skill level may help avoid potential shortages in a workforce which needs to have sufficient skills to support the renewable energy transition (see e.g. the discussion in Lucas et al. 2018). The requirements for high- and medium-skilled labour are of particular importance since they typically require longer-term training and a necessary skills-based infrastructure (vocational training, research and development, etc.), possibly resulting in adapted education curricula in related fields (see, for example, Comodi et al. 2019). The lack of an adequate education supply could thus form another potential barrier to the deployment of renewable energy if not addressed in advance. We therefore suggest that models dealing with the transition to renewable energy and its impact on employment should pay systematic attention to the requirements of renewable energy sources for different skill levels (as done, for example, at detailed sectoral level, by occupation and educational qualification, by Allan and Ross (2019) for the UK). An input-output framework combined with EXIOBASE 3.6 allows such a step forward as Allan and Ross (2019) also illustrate.

2.3 Existing EU analyses

The European Commission Joint Research Centre (JRC) report ‘Employment in the Energy Sector’ also identifies the projected employment effects of the green transition to be net positive (Czako 2020: 3). According to the findings summarised in the report, the ‘transition to a low-carbon economy is estimated to be positive for the EU as a whole, both in terms of GDP and employment growth. Compared to a business-as-usual baseline, until 2030 GDP and employment show growth of 1.1 % and 0.5 % respectively’ (Czako 2020: 17; Lewney et al. 2019). Furthermore, ‘[d]irect jobs in “Electricity supply” reached over 953 000 in the EU-28 in 2017’ (Czako 2020: 19). Latvia, Estonia, Denmark and Finland are the leading countries in terms of renewable energy employment per capita, predominantly biomass in Latvia, Estonia and Finland, and wind energy in Denmark (Czako 2020: 22).

The most recent ESDE report (European Commission 2021) advocates a ‘twin transition’ – tying the green transition together with the digital transition with regard to the recovery of the EU economy after Covid-19 (European Commission 2021: 125). A similar link appears in other EU policy documents such as European Commission (2018) and the European Investment Bank (2021). In terms of skill requirements, this approach is in line with ‘digital skills [being] in high demand in the energy industry as a whole’, although there is an important argument that multidisciplinary knowledge will be required in order to establish ‘new business models and societal initiatives’ European Commission Joint Research Centre (Czako 2020: 44). The expected innovations in the energy sector and related training are therefore assumed to go beyond purely technological expertise.

3. Methods and materials

3.1 Input-output analysis (IOA)

An industry-by-industry input-output table provides a snapshot of an economy in a given year showing transactions among and within economic sectors. IOA allows the modelling of different scenarios representing various pathways of the energy transition and the deployment of different technologies alongside their environmental and socioeconomic (e.g. employment) impacts. IOA captures interindustry linkages and the measures which arise from such externally-imposed changes both directly (in the sector itself) and indirectly (upstream, supply chain) (Cella 1984; Kerschner and Hubacek 2009; Miller and Blair 2009). It also allows a tracking of the changes worldwide through international trade links in the case of a multi-regional input-output framework.

A major shortcoming is that IOA works with constant returns to scale and does not consider the substitution of inputs (Fragkos and Paroussos 2018). Moreover, some assumptions, such as 'homogeneity of outputs' or 'missing interactions between prices and quantities' pose limitations (Markandya et al. 2016: 1348). The method is therefore commonly suited to estimating short-term effects or to separating out the changes in an economic structure which are caused by specific variations in a given factor without taking into account other developments in the economy. Nevertheless, IOA can be used even for long-term scenario analysis as a framework which integrates different types of information. Instead of the endogenous modelling of technological change, we integrate exogenous information (i.e. the scenarios) and assumptions about the future developments of key parameters (such as installed capacity costs or the projected lifetime of technology) as well as changes in final demand driven by policies and other relevant factors. Abstracting from other developments in the economy puts the problem of homogenous outputs beyond the analytical scope.

The following explanation of IO basics builds to a large extent upon Markandya et al. (2016), Miller and Blair (2009) and Peters and Solli (2010). The core part is a symmetric industry-by-industry input-output table with one row and one column for each industry. The row shows the other sectors to which a particular industry delivers while the column shows the required inputs of that particular industry. These so-called intermediate transactions are usually measured in monetary terms[5] for a given time period, usually one year. Either we can have an IO table for a single region or a multi-regional IO table (MRIO) showing flows within and between regions (or, indeed, countries).

In addition to the transaction matrix, the IO table comprises a matrix of final demand with columns indicating consumption by government, households, non-governmental organisations, capital formation, changes in stocks and valuables and also, in a single-region IO table, exports. Summing the rows of intermediate transactions and the final demand matrices gives a column vector of total output in which the rows show the total output of each sector. Another part is the so-called value added block, which comprises rows listing non-intermediary inputs such as the consumption of capital, wages, subsidies, taxes and also, in a single-region IO table, imports. Finally, an IO table can be extended by socioeconomic and/or environmental data related to each sector's production (e.g. employed persons, hours worked, greenhouse gas emissions and land use). Figure 1 below shows the composition of all these parts in a simplified example of an IO table with two regions. Note that final demand is further broken down into different categories for each region.

Figure 1 **A simplified example of a multi-regional IO table with two regions (see description above and Eq. 1 below for an explanation of each element)**

		Region A	**Region B**	**Final demand**	**Total output**
		Industry 1 Industry 2 ... Industry n	Industry 1 Industry 2 ... Industry n		
Region A	Industry 1 Industry 2 ... Industry n	**Z**		**F**	**x**
Region B	Industry 1 Industry 2 ... Industry n				
Value added		**E**			
Extensions					

To keep the explanation simple, we describe the basic components of an IO table based on an example with just one region with n sectors, q final demand categories and r extensions. The main components of such a table, according to the description above, are as follows:

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[5] Although not necessarily so – they can also be captured in physical units such as tons.

Equation 1

$$Z = \begin{bmatrix} z_{11} & z_{12} & \cdots & z_{1n} \\ z_{21} & z_{22} & & z_{2n} \\ \vdots & & \ddots & \vdots \\ z_{n1} & z_{n2} & \cdots & z_{nn} \end{bmatrix} \quad F = \begin{bmatrix} f_{11} & f_{12} & \cdots & z_{1q} \\ f_{21} & f_{22} & & z_{2q} \\ \vdots & & \ddots & \vdots \\ f_{n1} & f_{n2} & \cdots & z_{nq} \end{bmatrix} \quad x = \begin{bmatrix} x_1 \\ x_2 \\ \vdots \\ x_n \end{bmatrix} \quad E = \begin{bmatrix} e_{11} & e_{12} & \cdots & e_{1n} \\ e_{21} & e_{22} & & e_{2n} \\ \vdots & & \ddots & \vdots \\ e_{r1} & e_{r2} & \cdots & e_{rn} \end{bmatrix}$$

Z represents the matrix of intermediate transactions (inter-industry as well as intra-industry, i.e. what the industry delivers to itself). Hence z_{ij} represents deliveries from sector i to industry j (in a MRIO table, this applies to each of the regions in the model). The matrix F denotes final demand. Therefore, f_{ip}, an element of F, shows final demand for sector i's production by final demand category p. E is the extension matrix with r extension categories listed row-wise. Finally x is a column vector of length i giving the total output of all sectors:

Equation 2

$$x = Z\underline{1}_Z + F\underline{1}_F$$

where $\underline{1}_Z$ and $\underline{1}_F$ are column vectors of 1s, also called summation vectors, with lengths of n and q, respectively. This serves to sum the rows of Z and F.

The inter-industry flows from sector i to j in the Z transaction matrix depend on the total output required from sector j (the more electricity is produced, the more coal will be required where production is based on coal, for example). The so-called technical coefficients define the ratio of inputs to the total output of a sector (in other words, a 'recipe' of inputs per unit of output). If we denote technical coefficients matrix A with elements a_{ij}, then:

Equation 3

$$a_{ij} = \frac{z_{ij}}{x_j}$$

where x_j denotes the total output of sector j and a_{ij} denotes the inputs from sector i needed to produce one unit of sector j's output. Accordingly:

Equation 4

$$A = Z\hat{x}^{-1}$$

where $\hat{x}^{-1}$ is the inverse of the diagonal matrix of vector x, with the elements $\frac{1}{xi}$ placed on the main diagonal of a square matrix with zeros elsewhere, i.e:

Equation 5

$$\hat{x} = \begin{bmatrix} \frac{1}{x_1} & \cdots & 0 \\ \vdots & \ddots & \vdots \\ 0 & \cdots & \frac{1}{x_n} \end{bmatrix}$$

Therefore, if we substitute Z in Eq. 2 by $A\hat{x}$ derived from Eq. 4, we can write:

Equation 6

$$x = Ax + f$$

where $f = F\underline{1}F$ and is a column vector of the row sums of matrix *F*. From Eq. 6 we can derive the relationship of total output x and final demand f in the demand-driven Leontief model as:

Equation 7

$$x = (I - A)^{-1}f = Lf$$

and where:

Equation 8

$$L = (I - A)^{-1}$$

is the Leontief inverse matrix. The derivation of the Leontief matrix is described in detail in Section 8.2.

Finally we define employment intensity matrix M with elements m_{dj}, where d represents the six distributional employment categories obtained by distinguishing skill level and gender:

Equation 9

$$M = E(\hat{x})^{-1}$$

3.2 Data

3.2.1 Input-output data

The model works with data from EXIOBASE 3.6 (Stadler et al. 2018), the industry-by-industry version. EXIOBASE 3.6 is a global, multi-regional environmentally extended input-output database containing data for 1995-2016 dividing the global economy into 44 countries and five 'rest of the world' regions and 163 industries based on NACE Rev. 1 (Eurostat 1996). EXIOBASE 3.6 differentiates between 12 detailed electricity industries that allow the replacement of each other when modelling energy transition in the electricity industry.[6] EXIOBASE 3.6 has seven final demand categories[7] and contains gross value added together with the socioeconomic and environmental accounts as the extension matrix, denoted in Eq. 1 as E.

We can further disaggregate the production of electricity from wind into the production of electricity from wind onshore and from offshore; and the production of electricity from solar photovoltaic into the production of electricity from utility and from residential solar photovoltaic sources.[8] The IO tables we work with thus contain 165 industries in total with 13 electricity generation sectors. The disaggregation is motivated by the differences in installation costs for onshore and offshore wind; the different structural breakdown of capital expenditure (hereafter capex) for onshore and offshore wind, and for utility vs. residential solar PV (i.e. the absence of land rents in the case of residential/rooftop installations); and the different O&M employment factors for onshore vs. offshore wind and residential vs. utility solar PV. However, we have not changed the structure of inputs in the technical coefficients matrix and in the value added categories (mostly because of a lack of data for a reliable split).

3.2.2 Employment accounts data

The detailed industry resolution of the electricity sectors in EXIOBASE 3.6 has, however, been shown to be only approximate in terms of data precision in the case of (direct) employment accounts since the basis for disaggregation assumes equal employment per unit of value added for those industries where only aggregated employment data is available. Additionally labour intensity (per unit of output in millions of Euros) is not adjusted according to recent findings and has not undergone cross-source comparison with employment factors – that is jobs per MW installed – in respect of the operation and maintenance of electricity production as concluded by other studies (Cameron and van der Zwaan 2015; Ortega et al. 2020, 2015; Ram et al. 2020; Rutovitz et al. 2015). There seems to be a general imbalance in assumptions about employment in the production of electricity from non-renewable energy sectors in comparison with renewable energy ones. In particular, direct employment factors[9] (i.e. in operation and maintenance) are generally considered (see e.g. discussion in Lambert and Silva 2012) to be higher for renewable energy than

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[6] Note, however, that we do not model changes in the sector "Production of electricity n.e.c.", giving us 11 (though see following paragraph on disaggregation).

[7] Given the multi-regional structure, the column 'exports' is equal to zero as intermediate exports are endogenous in the model. Exports directly for final demand are determined by all other countries' imports of final demand.

[8] We classify power plants of over 1 MW of installed capacity as utility scale and below 1 MW as commercial/residential.

[9] Note that we are concerned here exclusively with direct employment concerning O&M related to the production of electricity from each source, not with employment related to installation and manufacturing (that is, linked through capital investments and the contributing sectors in the input-output logic). Employment should thus be equivalent to the O&M employment factors.

for the production of electricity from coal, gas and oil/petroleum, while this is almost the opposite in EXIOBASE 3.6.

Ram et al. (2020), using data from Rutovitz et al. (2015), Rutovitz and Harris (2012) and SolarPower Europe (2015), provide employment factors for electricity sources and technologies worldwide together with regional employment multipliers adjusted for labour productivity in each region. Given the similar structure of energy sources that Ram et al. (2020) consider, as well as the Europe-specific information they provide, we adopt the employment factors listed in their study. Table 1 shows a comparison of operation and maintenance employment factors calculated from the original EXIOBASE 3.6 employment data and in the light of data on installed capacity drawn from the EU 2016 Reference Scenario with the employment factors cited in Ram et al. (2020). It also shows what employment in each sector would look like.

Table 1 **Comparison of (direct, O&M) employment factors based on a weighted average for the EU-27+UK from EXIOBASE 3.6 and installed capacity from EU 2016 Reference Scenario for 2015, compared to the employment factors reported by Ram et al. (2020) if these data were used**

Region	Industry	Employment: Total (000) calculated using data from Ram et al. (2020) and Rutovitz et al. (2015)	O&M jobs per MW installed from Ram et al. (2020) and Rutovitz et al. (2015)	Employment: Total (000) from EXIOBASE 3.6	O&M jobs per MW installed from EXIOBASE 3.6 and EU 2016 Reference Scenario
EU27+UK	Production of electricity by coal	24.718	0.14	222.917	1.26
EU27+UK	Production of electricity by gas	30.748	0.14	174.171	0.79
EU27+UK	Production of electricity by nuclear	72.479	0.60	127.005	1.05
EU27+UK	Production of electricity by hydro	25.494	0.20	40.406	0.32
EU27+UK	Production of electricity by onshore wind	39.253	0.30	14.558	0.11
EU27+UK	Production of electricity by ffshore wind	2.148	0.20	1.349	0.13
EU27+UK	Production of electricity by petroleum and other oil derivatives	7.432	0.14	9.299	0.18
EU27+UK	Production of electricity by biomass and waste	41.863	1.50	23.269	0.83
EU27+UK	Production of electricity by utility solar photovoltaic	22.097	0.70	0.825	0.03
EU27+UK	Production of electricity by residential solar photovoltaic	92.217	1.40	1.531	0.02
EU27+UK	Production of electricity by solar thermal	0.004	0.60	0.134	18.56
EU27+UK	Production of electricity by tide, wave, ocean	0.021	0.60	0.004	0.12
EU27+UK	Production of electricity by geothermal	0.379	0.40	0.259	0.27

Source: residential solar photovoltaic – SolarPower Europe (2015) cited in Ram et al. (2020); all other energy sources – Rutovitz et al. (2015); EXIOBASE 3.6 data – Stadler et al. (2018); EU 2016 Reference Scenario installed capacity data – (Capros et al. 2016); own calculation

We further convert the employment factors from Rutovitz et al. (2015) and SolarPower Europe (2015) listed in Ram et al. (2020), based on jobs per MW installed, to jobs per million Euros of output of the electricity sectors using information for the total installed capacity of each source in the reference year of 2015 and the costs per MW installed. We input this information into the MRIO model as the starting point for our analysis.

We must point out that even the replacement figures are not perfect and should be interpreted with caution (see the comparison with European Commission Joint Research Centre (Czako 2020). However, the replacement numbers are, as a whole, more in line with existing research on the direct employment factors for each electricity source. For the sake of consistency, we choose to work with the full set of replacement employment factors rather than replacing only the most problematic parts (i.e. renewables). It is also important to keep in mind that employment factors are highly aggregated numbers and do not take into account country-specific situations, including not only geographical but also political factors such as, in particular, the role of ownership and the associated scale of renewable energy plants (especially but not exclusively PV). This may, in turn, further affect the accuracy of the employment factors.

3.2.3 GFCF data

In its basic form, the IO model would not be able to provide a detailed look at capital investments in the modelled electricity sectors because GFCF appears as one column in the final demand matrix F in the original IO tables. Since we aim to model capital investments in infrastructure related to the shift of electricity production from mostly non-renewable energy sources to renewable ones (scope and pace being dependent on the scenarios), the creation of separate GFCF columns for each electricity source is necessary.

To create separate GFCF columns, we first obtain data for installed capacity by each country and electricity source (for renewable energy and nuclear power from Eurostat (2021a, 2021b); for non-renewable energy sources from ENTSO-E (2021) and Kendziorski et al. (2020)). Where information is missing, we have supplemented the datasets with other sources.[10]

Second, we use data on costs per MW of installed capacity (current as well as projections, converted to million Euros per MW installed) drawn from the ETRI 2014 report (Carlsson et al. 2014) both for each country and each

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[10] These are Toshkin (n.d.) for Bulgaria; Cyprus Energy Regulatory Authority (2021) for Cyprus; Schlecht and Simic (2020) for Denmark; Ahola (2018) for Finland; countryeconomy.com (n.d.) for Malta; Lettner et al. (2018) for the Netherlands; and Bellini (2017) for Slovakia. Data regarding the production of electricity from each source in GWh on an annual basis come from Eurostat (Eurostat 2021c, 2021d) and, in the case of Cyprus, they also had to be supplemented with other sources (Cyprus Energy Regulatory Authority 2021).

source of electricity including coal, gas, nuclear, petroleum and oil, biomass and waste, solar thermal, tidal and wave, and geothermal energy; and from the International Renewable Energy Agency (hereafter IRENA) for onshore and offshore wind and for utility and residential solar PV (IRENA 2019). The ETRI 2014 data represent reference EU values and are calculated as a linear interpolation for 2015 (between 2013, the base year in the ETRI 2014 report, and a 2020 projection). The IRENA data represent a 2011-2019 weighted average (with a few minor exceptions where data for some years are missing) with country-level detail where possible and a country approximation where data for a specific country are not available. The country approximations follow the criteria of geographical proximity and/or similarity of size of economy (for detailed information, see Section 8.2.2). Since the IRENA data do not provide an outlook up to 2050, we use them as a starting point to derive future cost developments based on the ETRI 2014 data for the same sources (percentage changes in installation costs).

A detailed datasheet with information about installed capacity and costs per MW installed by country and electricity source in each considered year is available as additional information to this paper.[11]

Third, to distribute the installed capacity costs associated with the capital investments flowing into the modelled sectors, we use data for capex cost breakdown for each electricity source drawn from the ETRI 2014 report (Carlsson et al. 2014) and create a concordance matrix (see Table 4 in Section 8.2.1). Matching the cost breakdown with the EXIOBASE 3.6 industries through the concordance matrix is based on a detailed description of the breakdown categories given in Carlsson et al. (2014: 10) and finding the corresponding activities in the NACE rev. 1 detailed industry description (Eurostat 1996).[12] Note that, for some electricity sources (i.e. coal, gas, nuclear, petroleum and oil, biomass and waste, solar thermal, and tidal and wave energy), the ETRI 2014 report provides data for several technologies. Because information on installed capacity for each of these technologies is not available in satisfactory scope and detail, for modelling purposes we adopt the assumption of the 'most promising technology', i.e. the technology assumed to take on most of the production in the considered timeframe.

Fourth, to account for the costs of periodically renewed fixed capital – the replacement of old power plants, facilities and infrastructure – we use data on the lifetime of the expected operation of each electricity generating technology (see Table 2) according to the technology choices described above. To assure data consistency, we use projections from the ETRI 2014 report that are again assumed to fit typical geographical locations within the EU (Carlsson et al. 2014). We add the costs of capital replacement to the costs of newly-installed

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[11] GFCF.xlsx

[12] Some of the cost items had to be distributed among more EXIOBASE 3.6 sectors. In these cases (given the absence of detailed information), we have split these cost items proportionally between all the EXIOBASE 3.6 industries under consideration. This is typically the case for 'Project indirect costs' and 'Owner's costs'.

capacity assuming that, for example, if the lifespan is 20 years, then 1/20 is being reinstalled each year. Lifetime therefore indicates the time after which it is necessary to account for the costs of reinvestment (according to the installed MW).

Table 2 **Projected lifetime of each energy source (associated with respective EXIOBASE 3.6 industry) considered in the analysis according to ETRI**

EXIOBASE 3.6 industry (power plants based on the given technology)	2015	2020	2025	2030 onwards
Production of electricity by coal	40	40	40	40
Production of electricity by gas	30	30	30	30
Production of electricity by nuclear	60	60	60	60
Production of electricity by hydro	60	60	60	60
Production of electricity by onshore wind	20	22	23.5	25
Production of electricity by offshore wind	20	25	27.5	30
Production of electricity by petroleum and other oil derivatives	35	35	35	35
Production of electricity by biomass and waste	25	25	25	25
Production of electricity by utility solar photovoltaic	25	25	25	25
Production of electricity by residential solar photovoltaic	25	25	25	25
Production of electricity by solar thermal	30	30	30	30
Production of electricity by tide, wave, ocean	20	20	20	20
Production of electricity by geothermal	30	30	30	30

Source: Carlsson et al. (2014) [13]

The values in Table 2 are modelled under certain technological assumptions often taken from the Joint Research Centre Technology Map (see Carlsson and Vellei 2014). The consequence is that they cannot fully account for factors such as the legal situation affecting, for example, lifetime with a valid permit, replacement costs, insurance, waste management costs (which could be particularly relevant for nuclear power), etc., all of which together can have both negative and positive impacts on operational lifetimes.

3.2.4 Scenarios

The starting point for the model is the 2015 composition of energy sources in electricity generation and the 2015 capital investment in each electricity source. We compare the resulting job effects of a ‘minimum effort’ EU 2016 Reference Scenario (Capros et al. 2016) with the Stanford WWS Scenario (Jacobson et al. 2017; Mark Z. Jacobson et al. 2019). Both scenarios provide projections of gross electricity generation and net generation capacity by each electricity source until 2050 with a similar source structure as the sectors in

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[13] Values for 2015 are based on an interpolation between 2013 and 2020 since the original data are for 2013.

EXIOBASE 3.6. The authors of the Stanford WWS Scenario also provide their own calculations of the employment effects. These are primarily relevant to our discussion in Section 5 since the purpose of our study is to integrate data from different types of scenario (modelled under different assumptions and using different methods) into a single input-output framework that can distinguish more detailed distributional effects on employment as outlined above.

The EU 2016 Reference Scenario serves as a benchmark projection based on a price-driven market equilibrium approach (Capros et al. 2016, p. 15). This is modelled under the assumption of achieving 2020 climate and renewable energy targets in EU countries and following the policies adopted at EU and member state level until the end of 2014 and, in three cases,[14] until early 2015 (Capros et al. 2016, p. 14). In terms of justifying the resulting electricity mix, the scenario assumes that 'penetration of new technologies is dependent on their techno-economic characteristics alongside other drivers such as relative prices and costs, policies to promote energy efficiency, renewables and new technologies and broader market trends regarding economic efficiency and better use of resources' (Capros et al. 2016, p. 40). The scenario uses different learning curves for each considered electricity source assuming that '[…] all power technologies known today […] improve in terms of unit cost and efficiency, without however assuming breakthroughs in technology development' (Capros et al. 2016, p. 43). Non-mature technologies are assumed to be subject to 'substantial research and demonstration effort to enable economies of scale' (Capros et al. 2016, p. 41). The key policies modelled in the EU 2016 Reference Scenario are the EU Emissions Trading Scheme (ETS) (Capros et al. 2016, p. 26); the Energy Efficiency Directive (EED) (Capros et al. 2016, p. 27); legally binding targets on RES ('20% share of gross final energy consumption from RES by 2020 and 10% specifically in the transport sector' (Capros et al. 2016, p. 29)); and legally binding national GHG emissions targets covered by the Effort Sharing Decision (ESD) (Capros et al., 2016, p. 30). In terms of socioeconomic assumptions, the EU 2016 Reference Scenario assumes a moderate increase in the EU population; a 1.2 per cent annual GDP growth rate until 2020 and 1.5 per cent thereafter; and a growing role for the services sector (Capros et al. 2016, pp. 33–35).

The updated 2019 version of the Stanford WWS Scenario is a Green New Deal (GND) compatible pathway to reach 100 per cent renewables – namely onshore wind, offshore wind, hydropower, solar photovoltaic, solar thermal, tidal and wave, and geothermal energy – by 2050 (Jacobson et al. 2019). The 2017 version is not related to any specific policies but, in general, advocates policy measures towards higher energy efficiency, the deployment of RES and electrification (Jacobson et al. 2017). The common target of both versions is, however, a transformation of the energy system to keep global warming

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[14] These include the Indirect Land Use Change (ILUC) amendment to the renewable energy sources and Fuel Quality Directive (FQD) Directives and the Market Stability Reserve Decision amending the Emission Trading Scheme (ETS) Directive (Capros et al. 2016, p. 26).

below 1.5°C. The WWS roadmap is one of the possible (feasible) end-state mixes modelled in order to reach this climate target. The roadmap evaluates the feasibility and impacts of the GND energy component but does not explicitly take into account other policies included in GND (Jacobson et al. 2019: 450). The number of electricity generators needed to cover electricity production is derived from resource availability and the technical potential of each of the considered electricity sources (Jacobson et al. 2017: 38). The scenario starts with 2012 energy use and is based on a 20 per cent conversion rate (i.e. to power supply by WWS) by 2020; 50 per cent by 2025; 80 per cent by 2030; and 95 per cent by 2040. We interpolate values for 2035 and 2045 to capture the situation each five years in the 2015-2050 period and insert values for 2015 from the EU 2016 Reference Scenario to ensure the same starting point for both scenarios as well as the figures for electricity generation and net generation capacity. In order to simplify the assumptions, we assume the same conversion rates in both installed (nameplate) capacity and in end use (electricity generation) in the case of the Stanford WWS Scenario. In terms of socioeconomic development the study assumes moderate economic growth as well as population growth (Jacobson et al. 2019: 461), both taken (and adapted) from the US Energy Information Administration (EIA) (Conti et al. 2016).

The Stanford WWS Scenario is based on electrifying all the energy-using processes that can be electrified within the assumptions of the model (the rest refers to heat on the basis of existing technology) and therefore results in a significant increase in electricity production (Jacobson et al. 2019). The EU 2016 Reference Scenario also projects some (but far less ambitious) electrification of energy-using processes (see e.g. Capros et al. 2016, p. 50). We do not model the substitution effects in order to see only a subset of the labour demand associated with each electricity generation sector; electrification will certainly crowd-out some employment related to the other fuels that would be replaced by electricity, therefore decreasing overall labour demand.

Table 3 **Selected key differences between the EU 2016 Reference Scenario and the Stanford WWS Scenario**

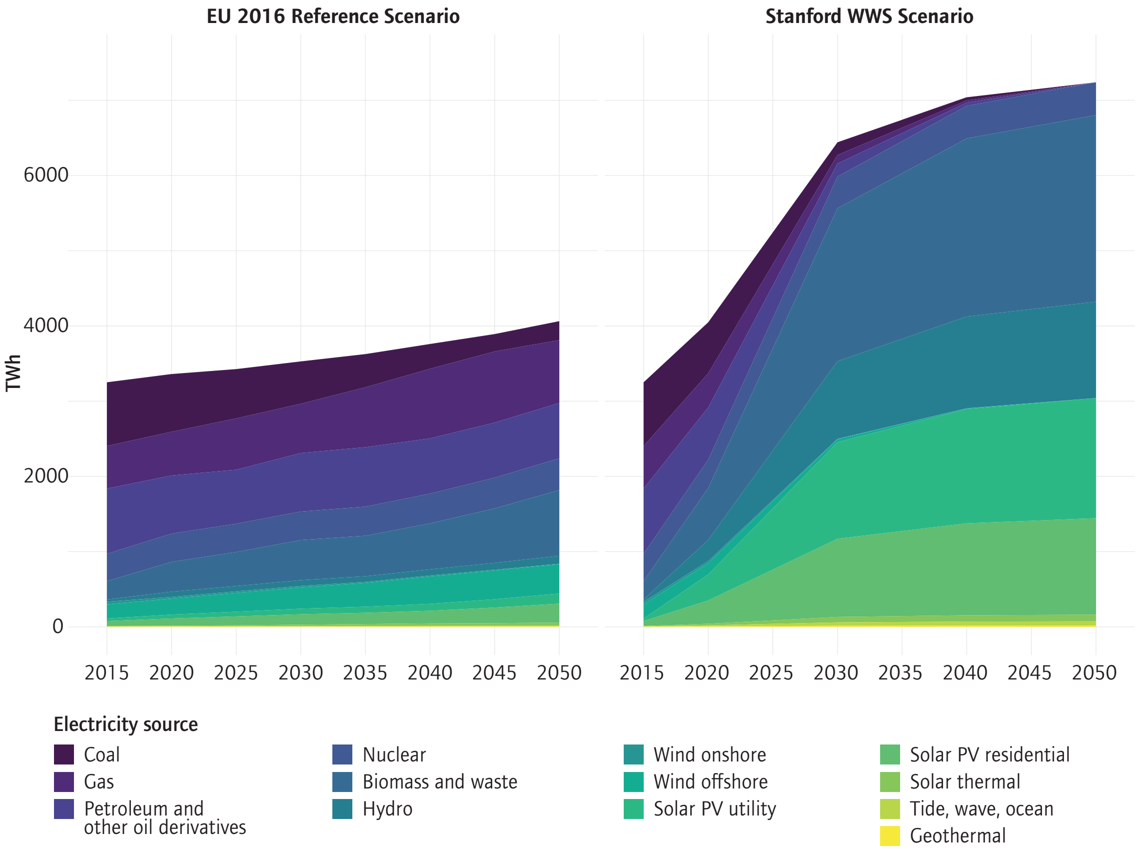
Selected key differences between the scenarios – summary		
	EU 2016 Reference Scenario	Stanford WWS Scenario
Total electricity production by 2050	4,063,717 GWh	7,238,915 GWh
End-state mix of electricity sources based primarily on…	Price-driven market equilibrium	Technological and economic feasibility (resource availability and technical potential)
Socioeconomic assumptions	Moderate economic growth, population growth	Moderate economic growth, population growth
Related policies or policy proposals	EU Emissions Trading Scheme (ETS); Energy Efficiency Directive (EED); legally binding targets on RES; legally binding national GHG emissions targets covered by the Effort Sharing Decision (ESD)	2017 version: no specific policies but advocating policy measures towards greater energy efficiency, deployment of RES and electrification; 2019 version: Green New Deal

Source: Capros et al. 2016; Jacobson et al. 2017; Jacobson et al. 2019

Figures 2 and 3 below show a comparison of the two scenarios first in terms of electricity production by each source (Figure 2) and then by new installed and replaced capacity by source (Figure 3). The yearly new installed capacity and replaced capacity are derived from projections of total installed capacity under each scenario. Whereas the values in Figure 2 to a large extent determine operation and maintenance-related labour demand, the numbers in Figure 3 influence the employment effects linked to capital investments.

A detailed datasheet containing information about installed capacity in MW and GWh of electricity generation under each scenario, each country and electricity source and in each considered year is available as additional information to this paper.[15]

Figure 2 **Electricity generation by source in TWh; comparison between EU 2016 Reference Scenario and Stanford WWS Scenario**



Source: Capros et al. 2016; Jacobson et al. 2019

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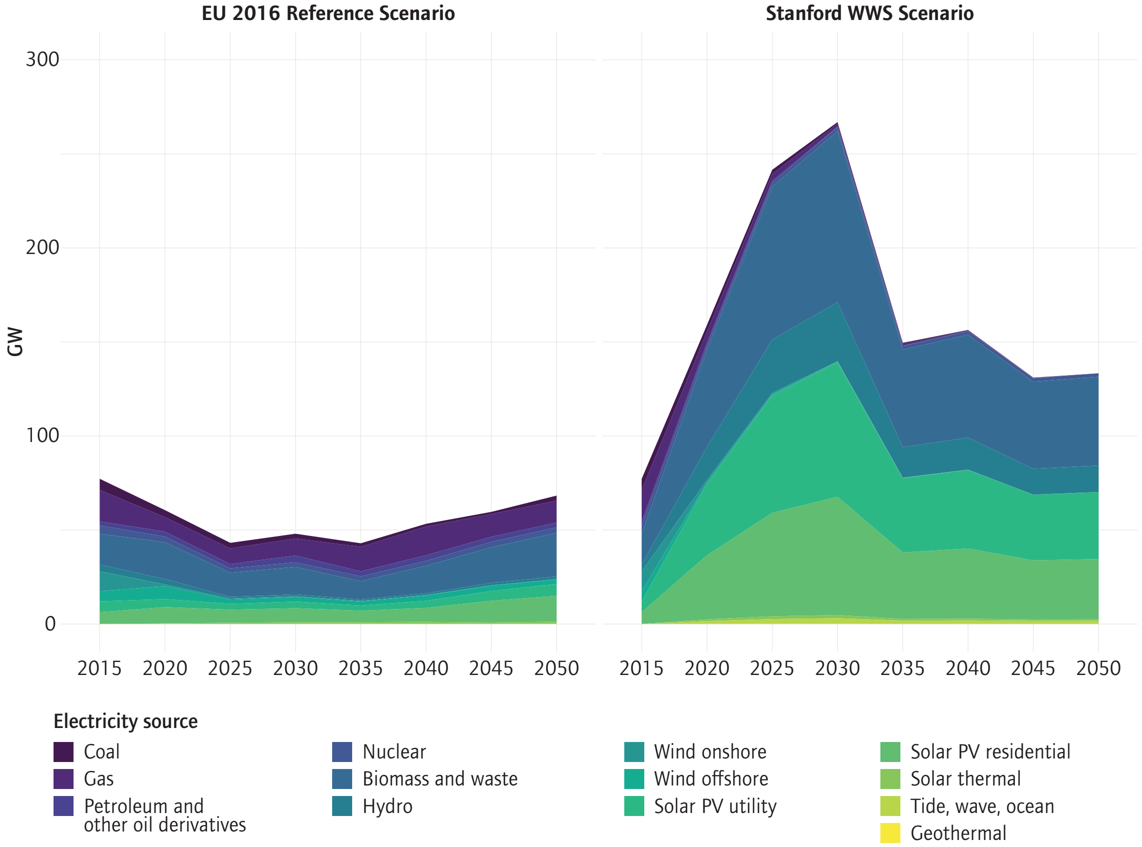
[15] Scenarios.xlsx

Figure 3 **Yearly new installed and replaced capacity by electricity source in GW; comparison of values derived from EU 2016 Reference Scenario and Stanford WWS Scenario**



Source: Capros et al. 2016; Jacobson et al. 2019 and the sources for installed capacity listed in Section 3.2.3 (GFCF data)

3.3 The input-output model

3.3.1 Disaggregation of electricity sectors

To prepare the IO data for the model, we start by disaggregating the original EXIOBASE 3.6 wind and solar PV electricity sectors as suggested in Section 3.2.1. The disaggregation of the rows and columns of these sectors in Z, F and E is carried out in proportion to the total output in GWh from the more detailed sectors. Data on electricity production in each of the disaggregated sectors are derived from Eurostat for 2015 (Eurostat 2021d).[16] The disaggregation is made only for the EU27+UK. While this type

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[16] Note that we are pairing different datasets together here. Since the primary source of data for electricity generation (in GWh) and for installed capacity (in MW) is the EU 2016 Reference Scenario, we would have used this instead of Eurostat if such a level of detail, distinguishing between onshore and offshore wind, and utility and residential solar PV utility, had been available. Because it is not, we had to use additional sources to disaggregate.

of disaggregation has no impact on the calculations, it is essential for the scenario analysis and the E matrix is modified in the next step of the model derivation.

3.3.2 Adjustments of the employment accounts in the electricity sectors

The second step consists of adjusting the employment accounts that are part of the extension matrix (E) in the sectoral columns. We replace the EXIOBASE 3.6 data on employment with data from Rutovitz et al. (2015) and SolarPower Europe (2015), as discussed in Section 3.2.2. Since these data lack detail on skill level and gender, we split it proportionally to EXIOBASE 3.6 across these categories. The resulting adjusted employment intensity matrix is denoted as M', distinguishing gender and three skill levels in six rows.

3.3.3 Integration of detailed capital investments in electricity sectors

In the third step, we include information on capital investments in each sector in the considered years. Using data for the costs of installed capacity (in million Euros per MW installed) discussed in Section 3.2.3, and distributing the values to individual rows (the payments of the modelled sectors for the creation of gross fixed capital), we create matrix K^t. This has detailed GFCF columns (k_{il}^t) for each modelled year t where l is a subset of sectors j representing the electricity sectors. We provide details of the calculation in Section 8.2.1.

3.3.4 Integration of the changes in electricity generation

The electricity mix as well as the overall levels of electricity generation depend on the country specific projections in the scenarios. To make sure that the model properly accounts for the production of electricity also in the case that the electricity mix in the base year did not contain a certain electricity source in a given country, we use the respective columns of technical coefficients as well as the employment intensities from another country. A full list of these replacements is included in Section 8.3. The replacements are based on criteria of geographical proximity or similarity of economic structure.

We calculate the total output x_l^t of electricity sector l in monetary units for each year t, assuming that it changes proportionately to electricity production g_l in GWh between the modelled year t and the previous year considered in the analysis (t–1), given by the scenarios:

Equation 10

$$x_l^t = (g_l^t / g_l^{t-1}) * x_l^{t-1}$$

Since in the following steps we only need the output of electricity sector l, we create vector x^t, composed of zeros and x_l^t at the appropriate positions for the electricity sectors.

3.3.5 Calculation of the employment effects

We calculate the upstream employment of electricity generation utilising data on total electricity output. To avoid double counting, we set the rows of electricity sectors in matrix A to zero (for the modelled countries). The modified matrix (hereafter denoted as A') is used to derive the modified Leontief inverse matrix L' applied in the calculations. Matrix A containing the intermediate input coefficients remains unchanged over time (and so does A'), assuming that the technology of production does not change over time in the model, and thus the Leontief inverse also remains the same. In this we see only the effects of the modelled changes within the electricity sector.

Finally we calculate the employment effects for each year t considered in the analysis, separately for each of the two interplaying effects considered above (i.e. the effects of capital investments Rk^t and of the overall change in electricity production from each source Rx^t). We calculate the employment effects of electricity production according to each scenario for each year t:

Equation 11

$$Rx_d^t = \widehat{m'}_d L' x^t$$

To obtain additionally the employment effects of capital investments (denoted as Rk^t), we proceed with the detailed GFCF matrix with columns for each electricity source K^t (specific for each modelled year t):

Equation 12

$$Rk_d^t = \widehat{m'}_d L' K^t$$

4. Results

We present here our results for the EU27+UK as a whole (Sections 4.1 to 4.5) and by country (Section 4.6), bearing in mind that the values for each respective year considered in the analysis represent a snapshot; a static representation of the situation in that year in terms of the number of jobs. In detail, Section 4.1 shows the results for employment related to O&M vs. capital formation; Section 4.2 provides results for the EU27+UK vs. the spill-over effects abroad triggered by expenditure in the EU27+UK; Section 4.3 shows the distributional effects by skill level and gender; Section 4.4 shows the results by sector; and Section 4.5 provides the results for each electricity source. Finally Section 4.6 shows the relative change in employment (increase/decrease in per cent) related to the electricity sectors in each country in the EU27+UK compared to the 2015 values. Detailed tables for all the figures in this section are listed in Section 8.4.1; while the results at country-level detail for employment by O&M vs. capital investments are available in Section 8.4.2. In the case of the O&M vs. capital formation effects and effects by energy source, we show both these for the EU27+UK and globally (denoted as 'rest of the world'). This is motivated by the effort to show the extent to which each energy source and the different lifecycle stages (i.e. O&M or capital formation) influence domestic employment vs. the spill-over abroad.

It is important to note that we do not model changes in the electricity mix outside the EU27+UK and therefore do not track employment taking place within the EU27+UK but associated with the O&M or GFCF of electricity sectors in other countries. At the same time, the simplified assumption that the mix of electricity sources in the rest of the world remains unchanged would imply that employment induced by O&M and capital formation in the electricity infrastructure in these countries remains constant over time.

Since each of the scenarios assumes different volumes of electricity generation (as well as installed net capacity), the results are not fully comparable if understood as 'what electricity mix brings more jobs'. Rather, they should be considered as two different pathways for the future of the electricity sector and its role in the overall EU27+UK economy, based on the assumptions lying behind each scenario.

4.1 Employment effects of operation and maintenance vs. capital formation

The overall labour demand by 2050 for the EU27+UK in the Stanford WWS Scenario (approximately 8.2 million jobs for O&M and GFCF combined) is more than twice as high as the EU 2016 Reference Scenario on the same basis (approximately 3.7 million jobs). Spill-over employment settles at more similar level in both scenarios (Stanford WWS Scenario again reports slightly higher labour demand) by 2050 but reaches multiple times higher levels in between in the Stanford WWS Scenario due to the effects related to capital formation.

O&M employment in the EU27+UK rises sharply until 2030 and then continues to grow at a moderate pace until 2050 in the Stanford WWS Scenario, resulting in more than 3.3 times more jobs (5.6 million) related to electricity production (in the electricity sector and upstream) compared to 2015. Even though O&M employment in the EU 2016 Reference Scenario also grows, the growth is rather linear and does not exceed 1.5 times the number of 2015 jobs by 2050 (below 2.5 million). In the rest of the world, O&M employment is within a comparable range in both scenarios (2.5 million jobs in the Stanford WWS Scenario and 1.9 million jobs in the EU 2016 Reference Scenario), which is in contrast to the rise of domestic jobs in the Stanford WWS Scenario.

GFCF jobs follow a different pattern. The Stanford WWS Scenario creates more GFCF jobs in general than the EU 2016 Reference Scenario – for example, approximately six times more in 2025 for employment within the EU27+UK. However, after the ‘wave’ culminates between 2025 and 2030, there is a sharp drop and a further decrease until 2050 when labour demand is again approaching the 2015 values. A very similar trajectory is observed for spill-over employment. GFCF employment in the EU 2016 Reference Scenario follows the opposite trend (declining after 2015 and only showing a slightly rising trend from 2035 on) and leads to approximately half the values of the Stanford WWS Scenario by 2050, both domestically and for the rest of the world. In total, the Stanford WWS Scenario induces GFCF-related labour demand which is 5-6 times higher around 2025 and 2030 compared to the EU 2016 Reference Scenario, but falls to only approximately 2 times higher in 2050.

Figure 4 **Direct and indirect employment effects related to changes in the energy mix in electricity production in the EU27+UK by capital formation vs. operation and maintenance (domestic vs. rest of the world)**

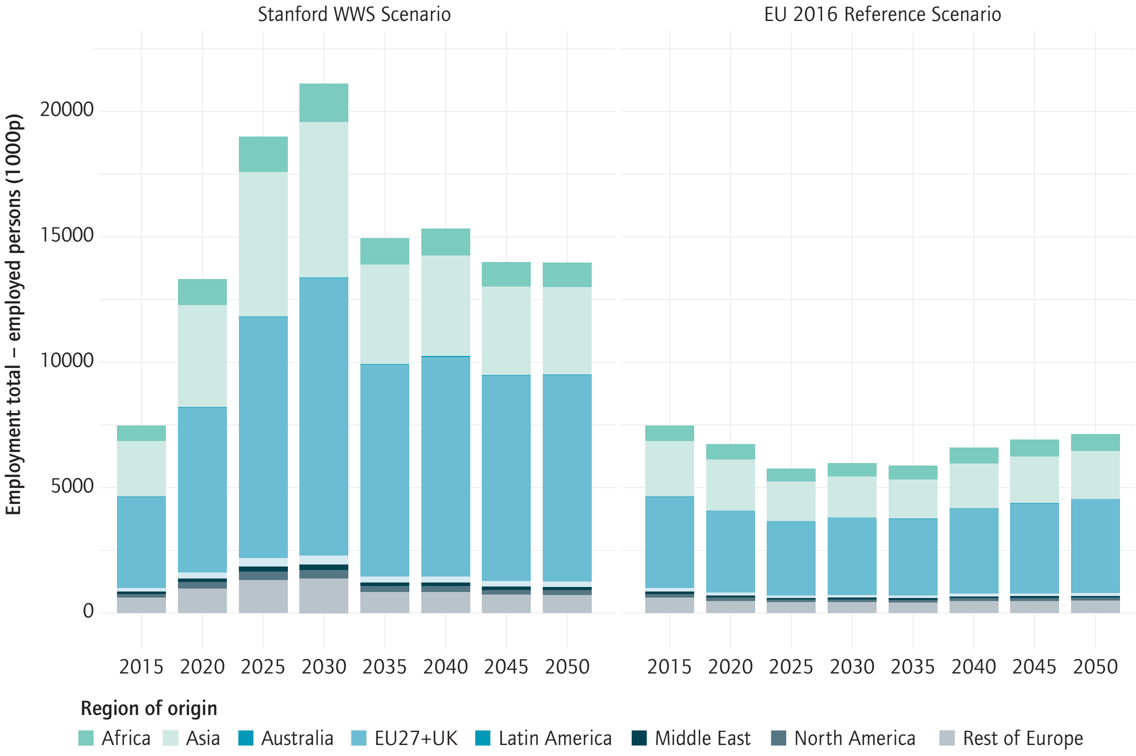
Source: EXIOBASE 3.6, Stanford WWS Scenario, EU 2016 Reference Scenario and the sources for employment accounts and installed capacity listed in Section 3, own calculation (Capros et al. 2016; Jacobson et al. 2019; Stadler et al. 2018)

4.2 Employment effects in the EU27+UK and abroad triggered by expenditure in the EU27+UK

In the Stanford WWS Scenario, all regions gain. The main beneficiary by far is the EU27+UK, with a 127 per cent increase in electricity related jobs by 2050 followed by Australia (+77 per cent), Africa (+60 per cent), Asia (+58 per cent), Latin America (+57 per cent), the Middle East (+39 per cent), North America

(+23 per cent) and the rest of Europe (+18 per cent). In the EU 2016 Reference Scenario, all regions except for Africa (+12 per cent) and the EU27+UK (+3 per cent) lose jobs by 2050 with North America being by far the biggest 'loser' by 2050 (-29 per cent), followed by Latin America (-20 per cent), the rest of Europe (-18 per cent), Asia (-14 per cent) and the Middle East (-13 per cent).

Figure 5 **Direct and indirect employment effects related to changes in the energy mix in electricity production in the EU27+UK and abroad triggered by expenditure in the EU27+UK**



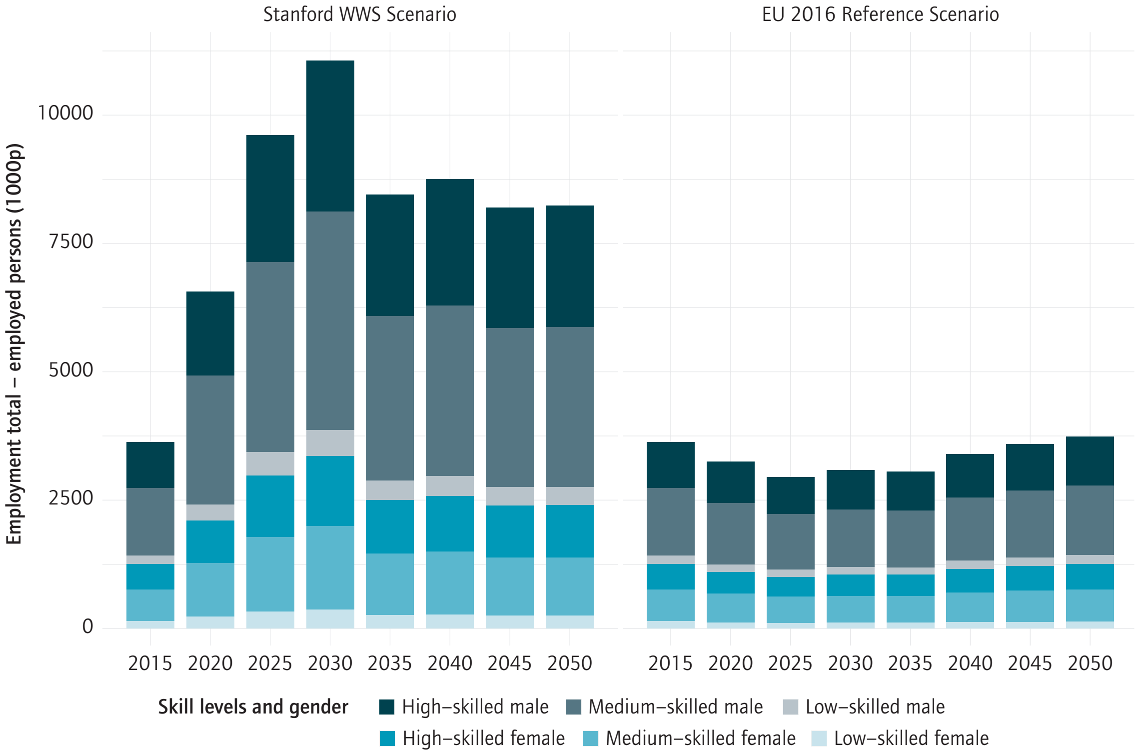
Source: EXIOBASE 3.6, Stanford WWS Scenario, EU 2016 Reference Scenario and the sources for employment accounts and installed capacity listed in Section 3, own calculation (Capros et al. 2016; Jacobson et al. 2019; Stadler et al. 2018)

Note that we do not model any changes by geographical origin concerning the spill-over employment effects. Therefore the results should be considered rather as a 'zero option' with no differences to the current international supply chain linkages. Nevertheless the results show that, even in the absence of any targeted policy by the EU (and the UK) attempting to allocate renewable energy supply chains domestically, the EU27+UK would benefit in both scenarios. In particular, the number of domestic O&M jobs is significantly higher in the Stanford WWS Scenario suggesting that, in terms of job creation, it is convenient to make the switch to renewables (and associated electrification in other sectors, as assumed in the Stanford WWS Scenario). This is in accordance with a majority of previous studies. The domestic job gains under the Stanford WWS Scenario are also clearly visible in the country-level breakdown as seen in Figure 11 (note that there we sum the O&M and GFCF employment effects).

4.3 Employment effects by skill level and gender

If the current structure of skill requirements and gender balance for each electricity source persists, the biggest share as well as the biggest increase (in the Stanford WWS Scenario) or the smallest decrease (in the EU 2016 Reference Scenario) would be occupied by high-skilled labour for men and women alike according to the projections. High-skilled male is the category with the relatively highest expected increase in the Stanford WWS Scenario (+165 per cent by 2050 and even +229 per cent by 2030 compared to 2015) and this is the one that also gains the most in the EU 2016 Reference Scenario (6 per cent). In the Stanford WWS Scenario, medium-skilled male (+137 per cent by 2050 compared to 2015) ranks second followed by high-skilled female (+107 per cent). Low-skilled labour would be the main 'loser' in both scenarios. The least benefiting category is low-skilled female, with +79 per cent in the Stanford WWS Scenario and -7 per cent in the EU 2016 Reference Scenario by 2050 compared to 2015 (in this scenario, it is the only category that loses). In the Stanford WWS Scenario, medium-skilled female follows (+83 per cent) whereas the second biggest 'loser' in the EU 2016 Reference Scenario is high-skilled female with 0 per cent change by 2050 compared to 2015.

Figure 6 **Direct and indirect domestic employment effects related to changes in the energy mix in electricity production in the EU27+UK by skill level and gender**



Source: EXIOBASE 3.6, EU 2016 Reference Scenario, Stanford WWS Scenario and the sources for employment accounts and installed capacity listed in Section 3, own calculation (Capros et al. 2016; Jacobson et al. 2019; Stadler et al. 2018)

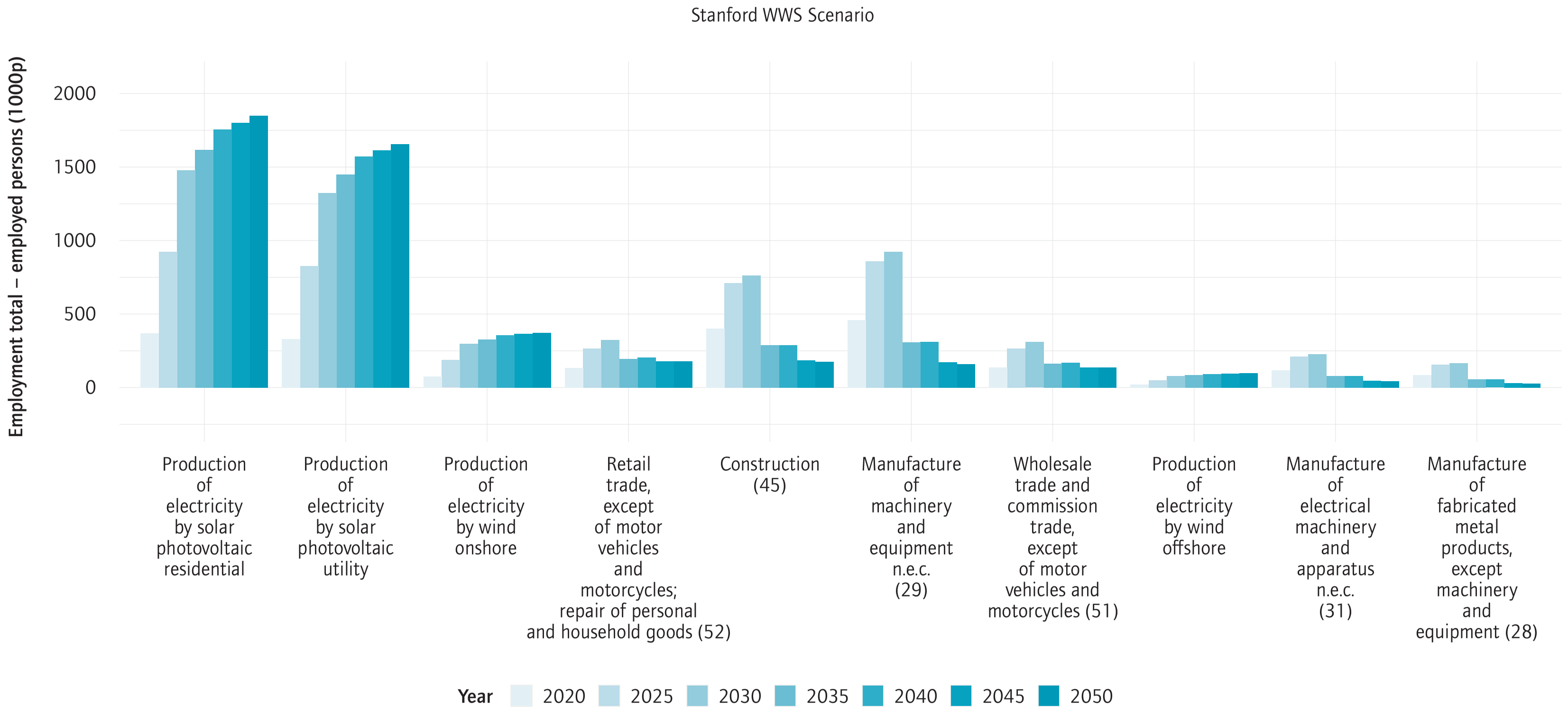
As for gender, there is an overwhelming male dominance throughout the analysed period. This means that, if the current gender imbalance in (and related to) the electricity sector is not addressed, male dominance associated with the sector would endure or even strengthen. At the same time, given that no changes in the proportions between different skill levels and gender are considered in the model, the resulting effects depend entirely on the mix of electricity sources and their current employment distribution structure. As such, the results should be seen as a 'zero option' if no targeted policy is adopted to tackle this imbalance.

4.4 Employment effects by sector

The sectoral breakdown follows a similar pattern as the overall employment for O&M and GFCF added together (see Section 4.1). In the Stanford WWS Scenario, there is a sharp increase at the beginning and then either a moderate one after 2030 or a drop back to lower levels in those sectors with the highest expected job gains (Figures 7a and 7b). A similar but reverse logic applies to many of the industries with the most significant employment declines (Figures 8a and 8b). In general, the most loss-making sectors are those associated with the production of electricity from fossil fuels. The sectors closely associated with the GFCF are a somewhat special case – the initial rise is followed by a fall back to lower levels or even a decline (see for example construction or manufacture of machinery and equipment n.e.c. – Figure 7 – or computer and related activities – Figure 8). Most of the effects observed in the EU 2016 Reference Scenario in the gaining sectors are more balanced in the sense that they start in the base year and continue at roughly the same rate until 2050. In the case of 'losing' sectors, there is usually a decline after 2015 and a recovery after 2030-35. This is especially true for the GFCF-related sectors, which also end up as the major 'losers' in this scenario. Production of electricity by residential solar PV is expected to gain the most in both scenarios, followed by utility solar PV, onshore and offshore wind in the Stanford WWS Scenario; and onshore wind, biomass and waste, and utility solar PV in the EU 2016 Reference Scenario. The average change in employment between 2015 and 2050 (see Figures 9a and 9b) offers a similar picture – the main 'winners' are the electricity sectors with the largest increase in the share in the electricity mix in both scenarios.

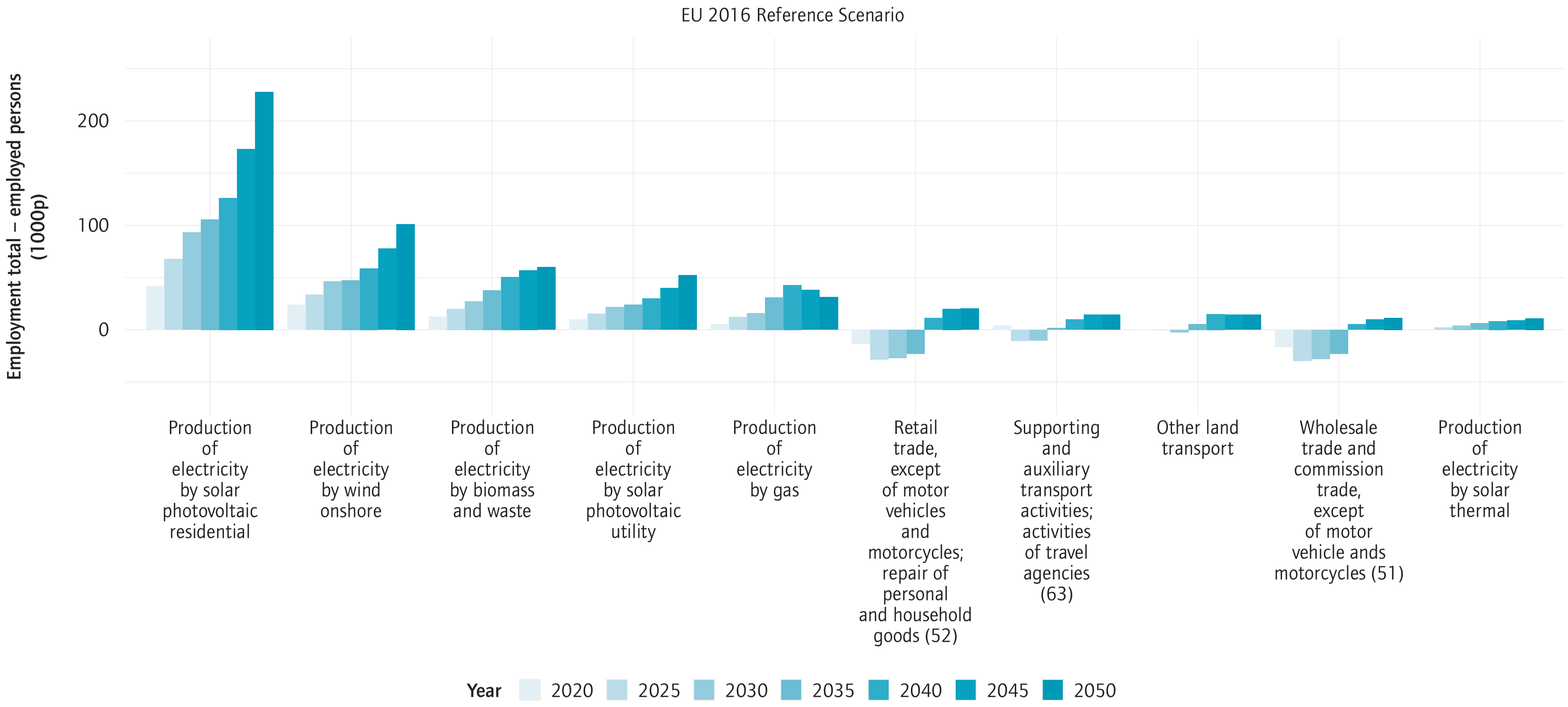
Let us stress that since EXIOBASE 3.6 works with very narrowly defined sectors, which in this case are divided by electricity sources, it may seem somewhat confusing that we report employment changes in the electricity sectors together with other sectors. For example, the sector "Production of electricity by solar photovoltaic residential" in Figure 7 consists entirely of the production of electricity by solar PV residential and shows employment directly in this sector. In contrast, what we show in Section 4.5 are the impacts along the entire upstream supply chains (i.e. direct and indirect together) that are induced by each source of electricity, but which appears as a sector (industry) in the EXIOBASE 3.6 structure.

Figure 7a **Employment effects related to changes in the energy mix in electricity production in the EU27+UK by sector – the ten sectors with the biggest increase (domestic)**



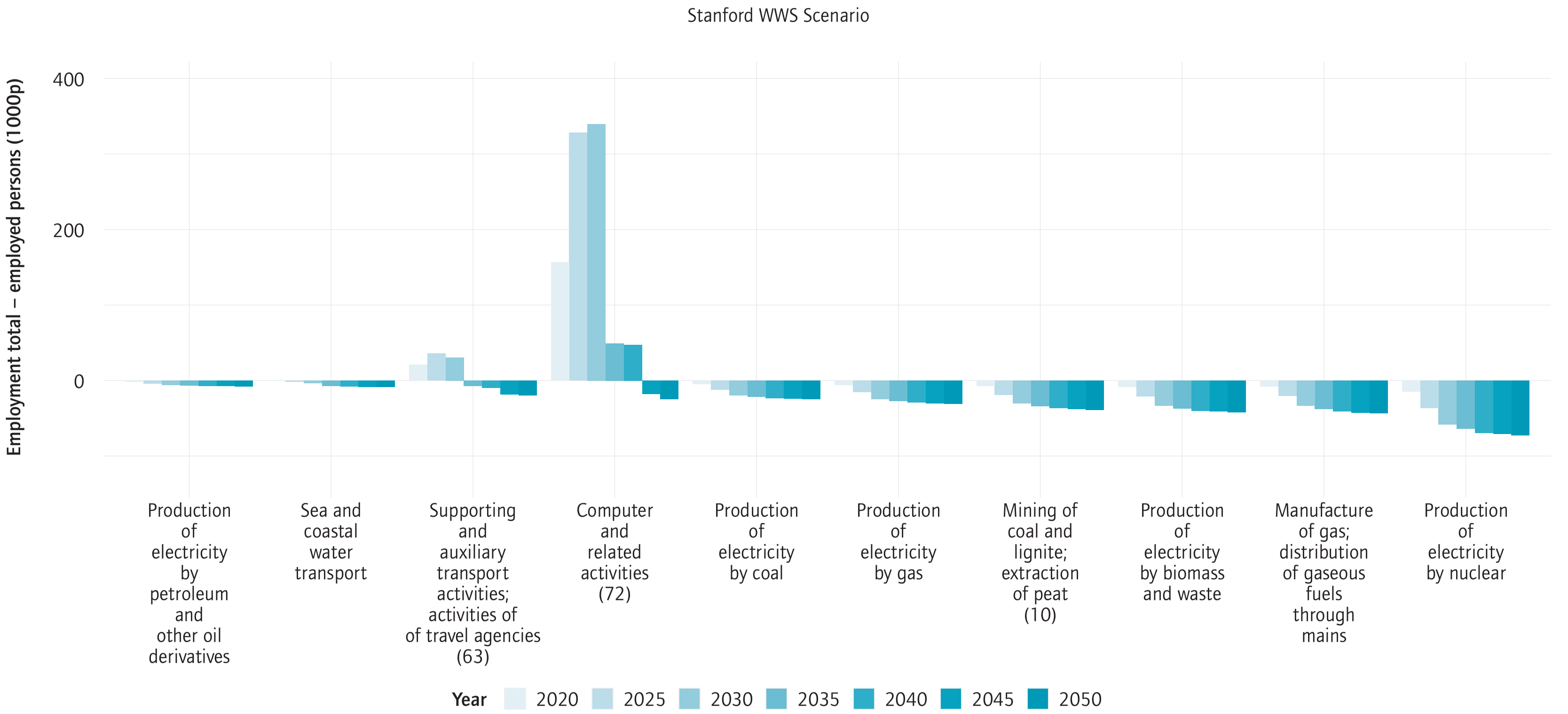
Source: EXIOBASE 3.6, EU 2016 Reference Scenario, Stanford WWS Scenario and the sources for employment accounts and installed capacity listed in Section 3, own calculation (Capros et al. 2016; Jacobson et al. 2019; Stadler et al. 2018)

Figure 7b **Employment effects related to changes in the energy mix in electricity production in the EU27+UK by sector – the ten sectors with the biggest increase (domestic)**



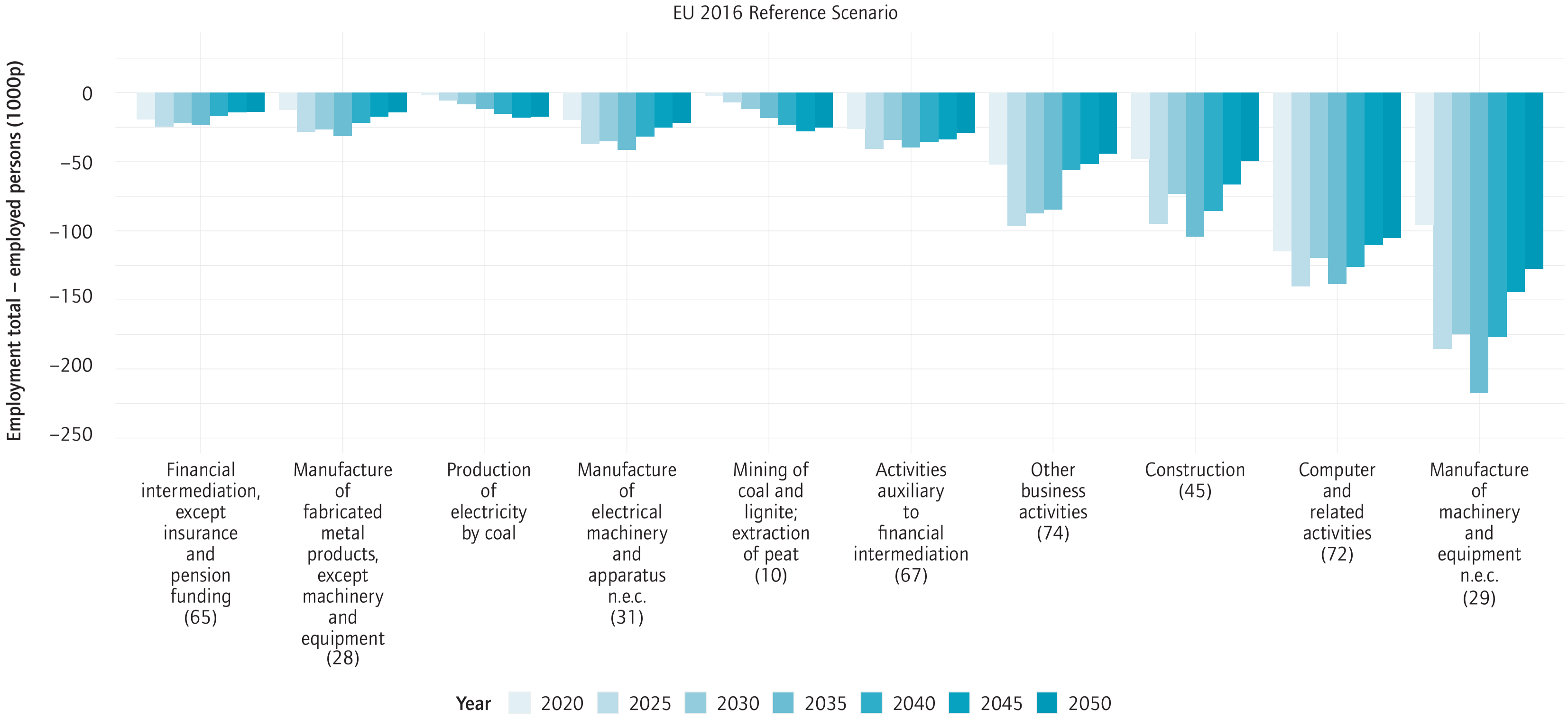
Source: EXIOBASE 3.6, EU 2016 Reference Scenario, Stanford WWS Scenario and the sources for employment accounts and installed capacity listed in Section 3, own calculation (Capros et al. 2016; Jacobson et al. 2019; Stadler et al. 2018)

Figure 8a **Employment effects related to changes in the energy mix in electricity production in the EU27+UK by sector – the ten sectors with the biggest decrease (domestic)**



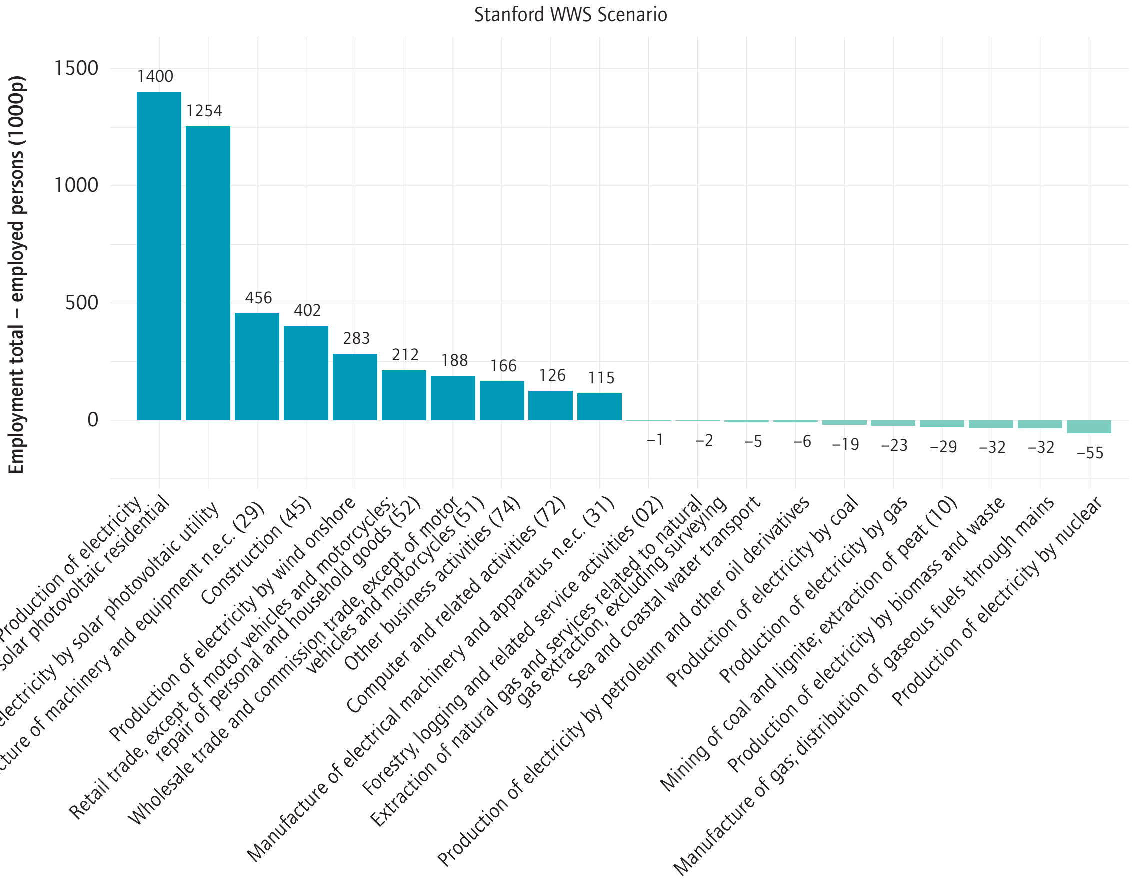
Source: EXIOBASE 3.6, EU 2016 Reference Scenario, Stanford WWS Scenario and the sources for employment accounts and installed capacity listed in Section 3, own calculation (Capros et al. 2016; Jacobson et al., 2019; Stadler et al. 2018)

Figure 8b **Employment effects related to changes in the energy mix in electricity production in the EU27+UK by sector – the ten sectors with the biggest decrease (domestic)**



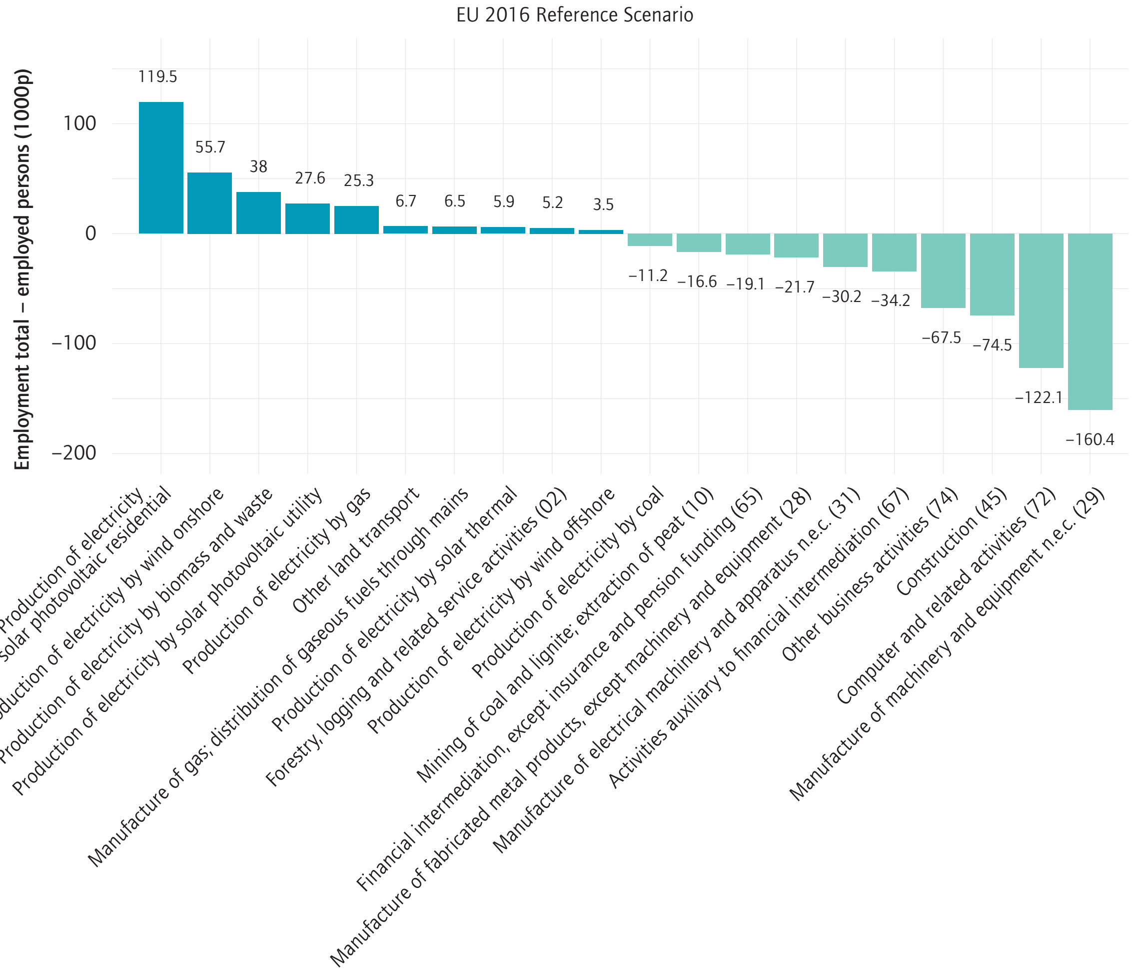
Source: EXIOBASE 3.6, EU 2016 Reference Scenario, Stanford WWS Scenario and the sources for employment accounts and installed capacity listed in Section 3, own calculation (Capros et al. 2016; Jacobson et al., 2019; Stadler et al. 2018)

Figure 9a **Employment effects related to changes in the energy mix in the EU27+UK by sector – average over the 2015-2050 period (domestic)**



Source: EXIOBASE 3.6, Stanford WWS Scenario, EU 2016 Reference Scenario and the sources for employment accounts and installed capacity listed in Section 3, own calculation (Capros et al. 2016; Jacobson et al. 2019; Stadler et al. 2018)

Figure 9b **Employment effects related to changes in the energy mix in the EU27+UK by sector – average over the 2015-2050 period (domestic)**

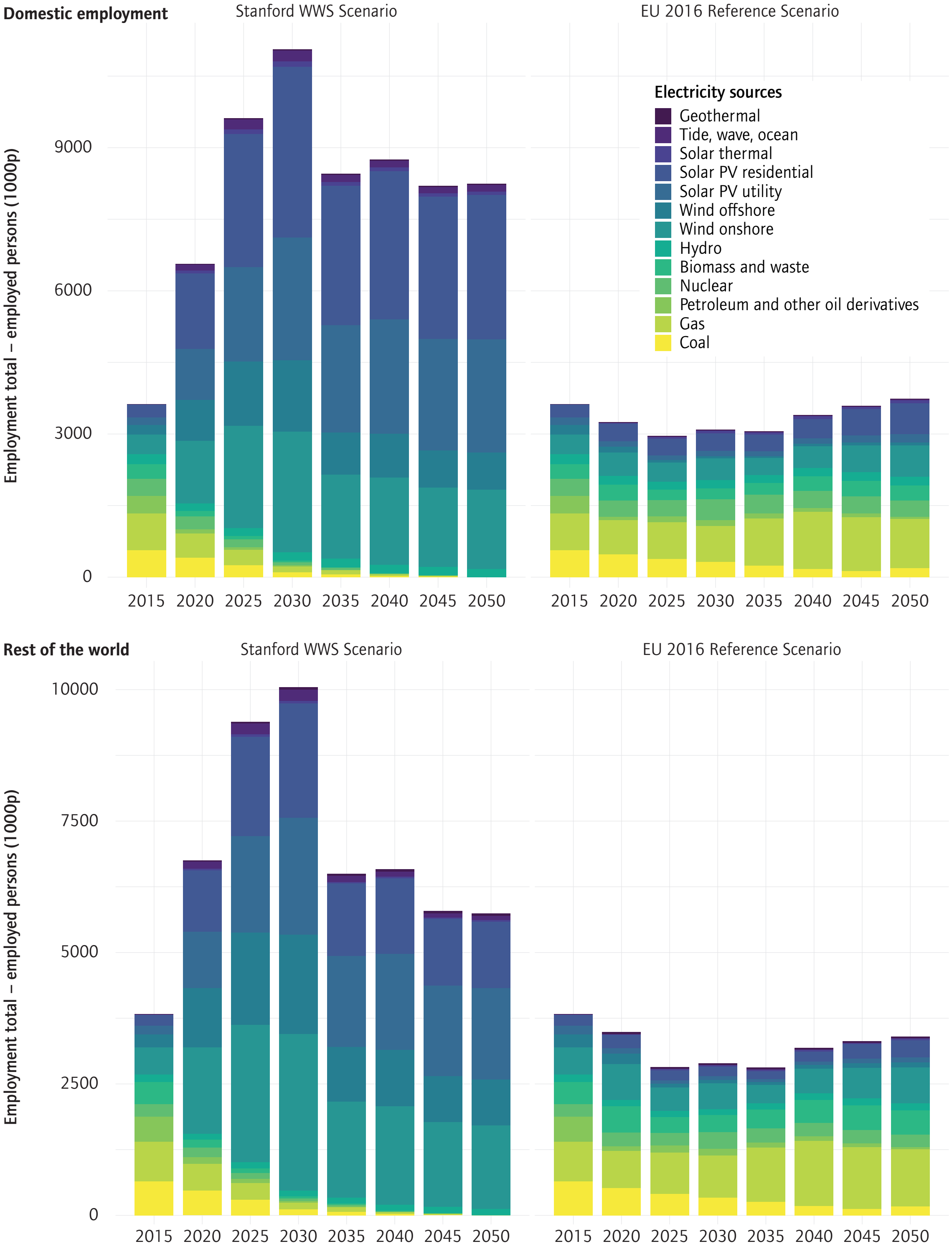


Source: EXIOBASE 3.6, Stanford WWS Scenario, EU 2016 Reference Scenario and the sources for employment accounts and installed capacity listed in Section 3, own calculation (Capros et al. 2016; Jacobson et al. 2019; Stadler et al. 2018)

4.5 Employment effects by electricity sources

In the Stanford WWS Scenario, the highest (direct and indirect together) number of jobs within the EU27+UK is generated in residential solar PV (3 million) followed by utility solar PV (2.4 million), onshore wind (1.7 million) and offshore wind (0.8 million) with the same four sources in the lead (in a slightly different order; see Figure 10) abroad. Utility solar PV may additionally dominate the Stanford WWS Scenario because of its higher O&M employment factor (1.4 per MW installed; see Table 1 in Section 3.2.2) compared to the other sources which have significant shares under this Scenario. In the EU 2016 Reference Scenario, gas dominates by 2050 within the EU27+UK (with approximately 1 million jobs) followed by onshore wind (0.6 million), residential solar PV (0.6 million), nuclear (0.3 million) and biomass and waste

Figure 10 **Direct and indirect employment effects related to changes in the energy mix in electricity production in the EU27+UK by each electricity source (domestic vs. rest of the world)**



Source: EXIOBASE 3.6, Stanford WWS Scenario, EU 2016 Reference Scenario, own calculation (Capros et al. 2016; Jacobson et al. 2019; Stadler et al. 2018)

(0.3 million). Gas also dominates employment abroad followed by onshore wind, biomass and waste, residential solar PV and nuclear.

Regarding the relative changes (percentage increase/decrease compared to 2015), the Stanford WWS Scenario anticipates the highest increase within the EU27+UK by 2050 to be for tidal and wave power followed by utility solar PV, residential solar PV and solar thermal energy. The tidal and wave power sector also dominates the spill-over effects abroad followed by utility solar PV and the geothermal power sector. The massive growth of jobs associated with electricity production from tidal and wave, solar thermal and geothermal power is likely to be due to their low share in the electricity mix in the base year. Even so, their role in the overall electricity mix remains relatively marginal in terms of the absolute number of jobs (see Table 8 in Section 8.4.1). Electricity production from solar thermal and tidal and wave power is also expected to undergo the highest domestic increase in labour demand under the EU 2016 Reference Scenario.

Recall that Figure 10 shows the direct and indirect employment effects together that are induced by each source of electricity, which in the EXIOBASE 3.6 structure corresponds to a sector (industry) – see note at the end of Section 4.4.

4.6 Employment effects by country

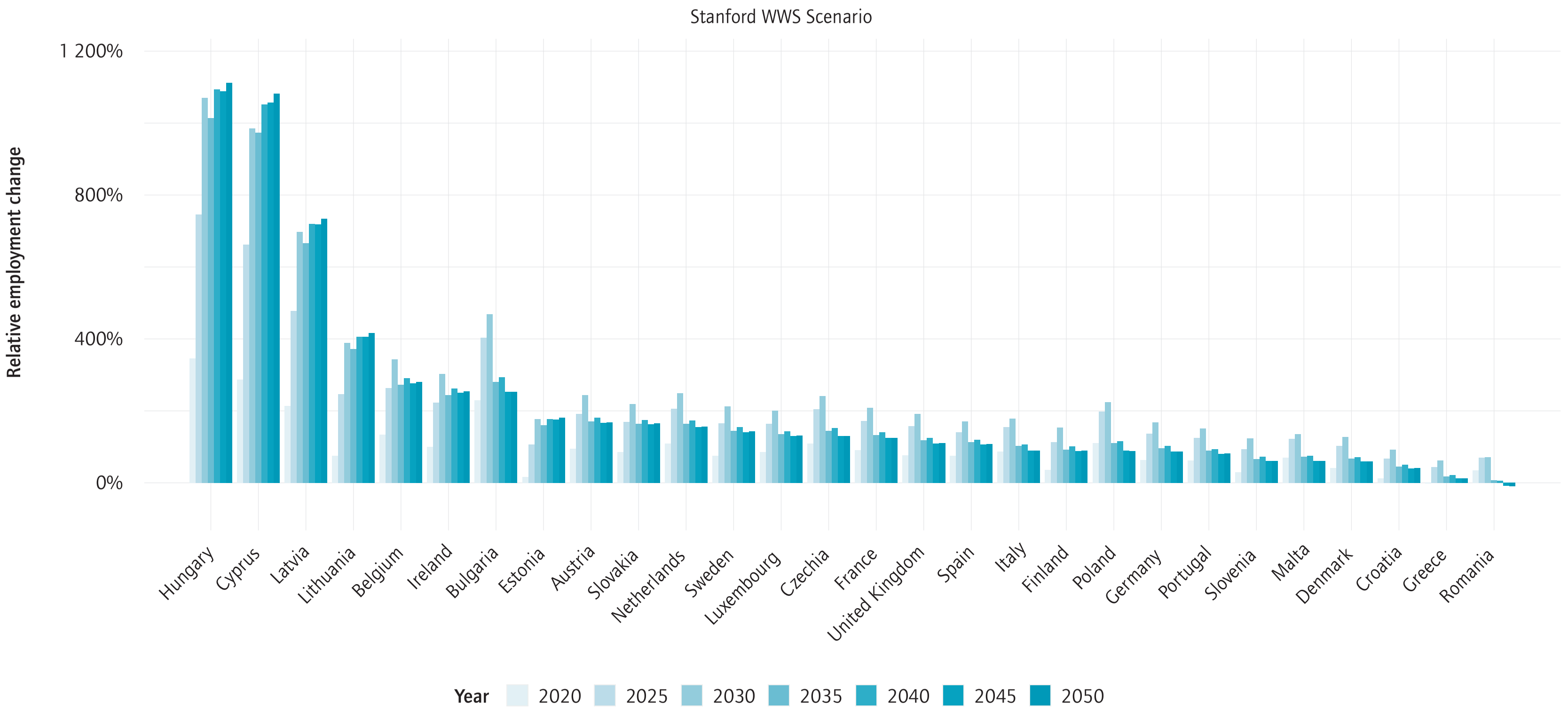
The Stanford WWS Scenario would trigger massive labour demand in most EU27+UK countries, rising sharply at the beginning of the transition and peaking around 2030 followed by either a slight decline or a steady state continuation. The major ‘winners’ by 2050 would be Hungary and Cyprus (over eleven and ten times more jobs in electricity sectors than in 2015), followed by Latvia (over seven times), Lithuania (a little more than four times) and Belgium (approximately three times as many). Only one country would lose jobs related to the electricity sectors by 2050 (-10 per cent in Romania).

The EU 2016 Reference Scenario shows that 15 countries would end up as net gainers and 13 as net losers. The biggest increase is expected in Slovenia (almost 1.5 times higher labour demand in electricity sectors by 2050 compared to 2015, with values 2.5 times higher by 2040) followed by Luxembourg (1.7 times higher by 2050) and Malta (1.6 times higher by 2050). Following these countries are Hungary (an increase of 56 per cent), Italy (32 per cent) and Slovakia (31 per cent). In contrast Lithuania, Estonia, Finland and Greece are expected to lose most jobs related to electricity – all over 50 per cent by 2050.

The projections in the case of the Stanford WWS Scenario show the largest increases in countries where: 1) there are currently relatively low levels of WWS deployment (i.e. the current mix relies on either fossil fuels or bioenergy); and 2) sources with relatively higher employment factors (compared to the 2015 mix of electricity sources) are expected to take on the majority of electricity generation. For example, this would apply to Cyprus with offshore wind and residential solar PV leading electricity production in 2050 (compared to petroleum and oil derivatives in 2015); to Hungary with solar PV (both residential and utility), onshore wind and geothermal; and to Latvia, again with solar PV (both categories) and wind (both onshore and offshore). In general the major winners are usually also those countries with the highest absolute expected increases in electricity generation which would be triggered (perhaps mostly, but not exclusively) by growing demand from other industries as given under the Stanford WWS Scenario. Since the results show direct and indirect employment changes together, the increase may also indicate the presence of parts of the supply chains in the production and installation of WWS sources of electricity (but this is uncertain and cannot reliably be asserted based on the results). Finally, the overall growth in electricity-related jobs is also driven by the increase in electricity consumption that the Stanford WWS Scenario assumes (see Section 3.2.4).

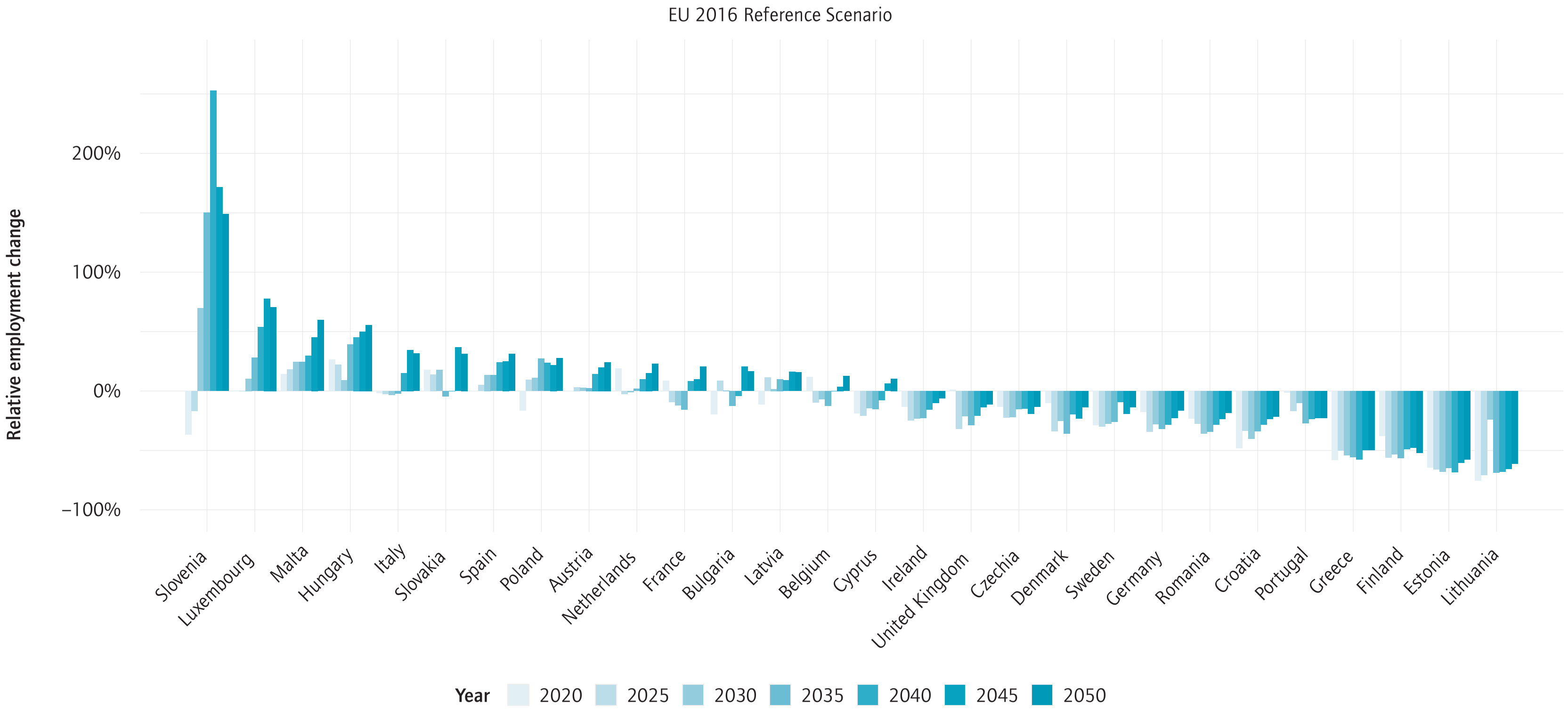
The figures from the EU 2016 Reference Scenario show two things in particular. First, most of the employment gains would be generated by the capital replacement of existing infrastructure which could be particularly significant for nuclear power plants (in the cases of Slovenia and Hungary). It is important to bear in mind that the Scenario does not foresee massive infrastructure changes but rather models nearly status quo development. The rest of the changes in labour demand thus depend on the changing mix of electricity sources and their respective employment factors and the associated supply chains – or their respective parts within EU27+UK countries. Total electricity demand - and therefore electricity generation - is also much lower in the EU 2016 Reference Scenario than in the Stanford WWS Scenario (again, see Section 3.2.4 for a discussion of the differences between the scenarios).

Figure 11a **Direct and indirect relative employment effects related to changes in the energy mix in electricity production in the EU27+UK by country (domestic; relative increase/decrease compared to 2015 values)**



Source: EXIOBASE 3.6, Stanford WWS Scenario, EU 2016 Reference Scenario, own calculation (Capros et al. 2016; Jacobson et al. 2019; Stadler et al. 2018)

Figure 11b **Direct and indirect relative employment effects related to changes in the energy mix in electricity production in the EU27+UK by country (domestic; relative increase/decrease compared to 2015 values)**



Source: EXIOBASE 3.6, Stanford WWS Scenario, EU 2016 Reference Scenario, own calculation (Capros et al. 2016; Jacobson et al. 2019; Stadler et al. 2018)

5. Discussion

5.1 'Nowcasting' comparison of the projections with current developments (2020 situation)

The scenarios incorporated in the model take 2015 as the baseline (mainly due to the time lag in reporting the relevant data), while the values for 2020 and beyond are already subject to projections. Consequently we start our discussion by comparing the projected values of electricity generation and installed capacity by source for the EU27+UK with the actual values and developments up to 2019, as reported by Eurostat (2021d, 2021c, 2021a, 2021b) and from ENTSO-E (2021) and Kendziorski et al. (2020), supplemented by other sources mentioned in Section 3.2.3.[17] We do not compare actual employment figures by electricity sector because data at such a level of comparative detail are not yet available (Eurostat only provides aggregate data for NACE Rev. 2 sector "Electricity, gas, steam and hot water supply" and a significant amount of detailed data at country level is missing). Figures 12 and 13 summarise developments up to 2019 and compare these with the values for 2020 in the two scenarios.

The out-turns generally correspond better to the EU 2016 Reference Scenario. However, there are a few exceptions. Coal's share of electricity generation is significantly lower than projected (467 305 GWh in 2019, according to Eurostat data, compared to 767 262 GWh as assumed in the EU 2016 Reference Scenario) while the share of gas has increased more than the Scenario assumed (696 719 GWh in 2019, according to Eurostat data, compared to 580 998 in 2020 as assumed in the Scenario). As far as the evolution of electricity generation is concerned, the other sources seem to correspond fairly well to the actual evolution (see Figure 12). The trends described above for coal and gas are also matched by trends in new installed and replaced annual capacity (i.e. not total installed capacity but the annual additions) – see Figure 13 – where the figures for both coal and gas follow the same trend (i.e. coal declining and gas increasing) up to 2019. In fact the share of installed capacity of gas plants is higher than expected in the scenarios. This indicates a trend of a shift from coal to gas in electricity generation. The graph of annual installed and replaced capacity also shows that PV (both utility and residential) is on a much stronger upswing than assumed in the EU 2016 Reference Scenario but still much lower than in the Stanford WWS Scenario.

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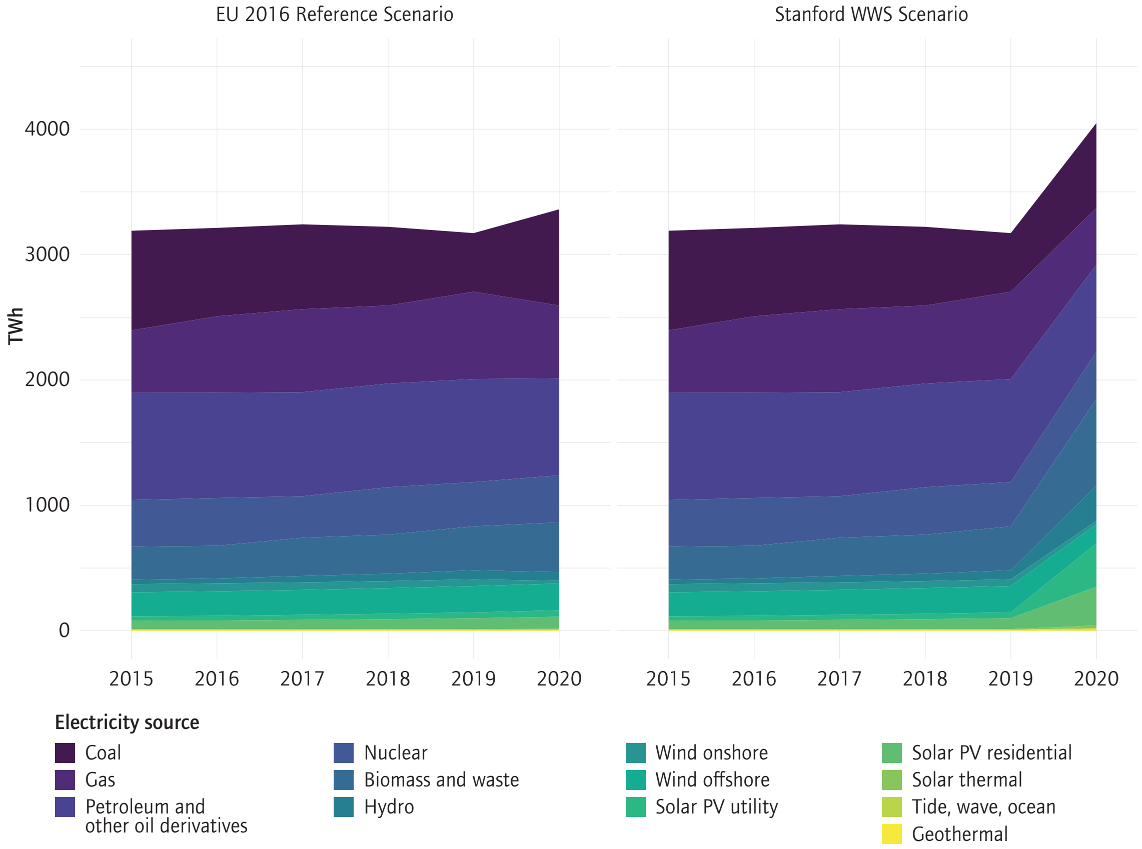
[17] 2019 is the latest available year with complete data from the respective Eurostat databases.

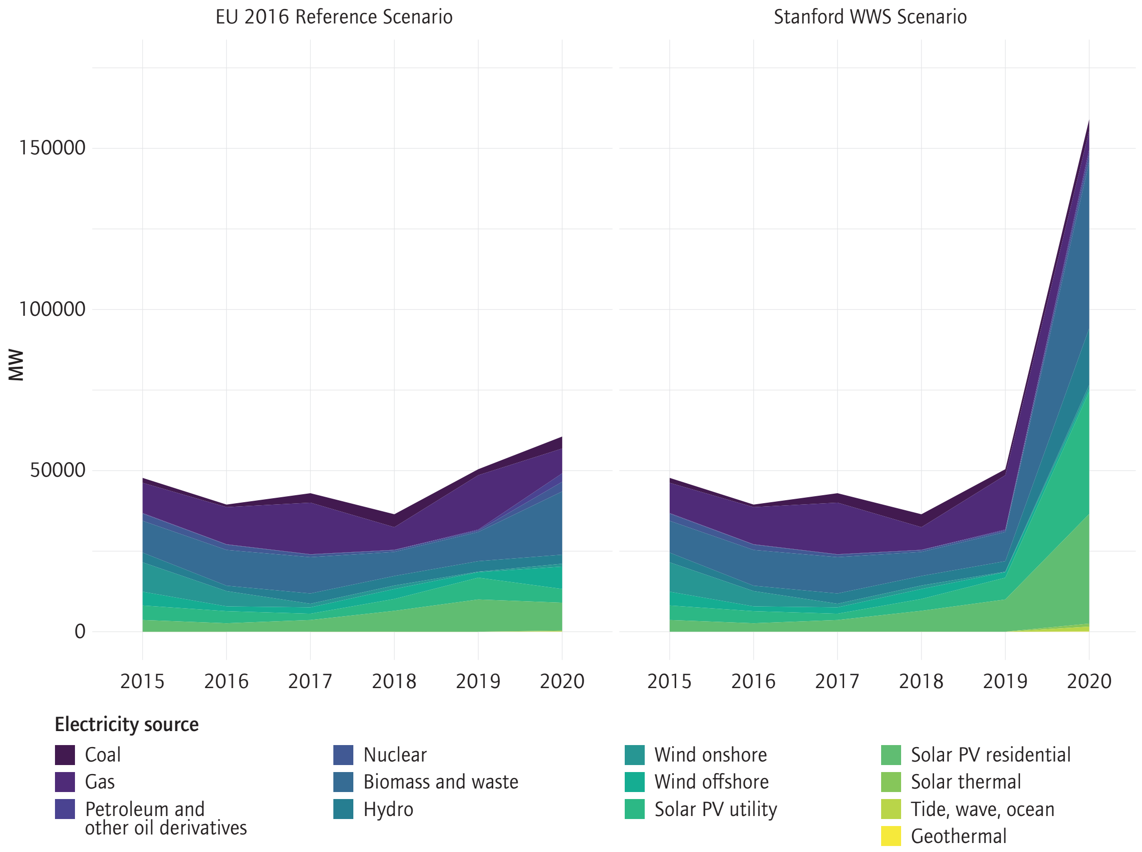
Figure 12 **Electricity generation by source: comparison of the 2020 projections for each scenario**



Sources: Capros et al. 2016; Jacobson et al. 2017 with the actual developments 2015-2019 from Eurostat (2021d, 2021c) and supplementary sources

So far, EU27+UK countries seem to be stalling when it comes to embarking on a massive transformation of the electricity sector towards a post-carbon one. The increasing installations of solar photovoltaics offer some promise in this respect, as does the apparent decline in coal-fired power generation (although it is unclear how this trend will be affected by the currently rocketing gas prices). It is not yet possible to assess the impact on employment changes due to the lack of sufficiently detailed recent data.

Figure 13 **Yearly new installed and replaced capacity by source; comparison of the 2020 projections under each scenario**



Sources: Capros et al. 2016; Jacobson et al. 2017 with actual developments 2015-2019 from Eurostat (2021a, 2021b), ENTSO-E (2021), Kendziorski et al. (2020) and supplementary sources

5.2 Policy implications

Given the main objectives of the analysis, i.e. to contribute to the debate on the skills required by a bold post-carbon transformation (here focusing on the electricity sector) in the EU27+UK, we suggest that policy-makers consider the following.

First, jobs related to the construction of new infrastructures (gross fixed capital formation) tend to be temporary and are created in sectors other than those involved in O&M supply chains. The Stanford WWS Scenario clearly divides the transition into two phases with the first characterised by massive capital investments and an associated employment 'wave'. This trend is consistent with the 80 per cent conversion to wind, water and solar energy by 2030 assumed by the Scenario, i.e. much faster changes in the electricity mix at the beginning than during the rest of the analysed period. At the same time, the trend followed by the EU 2016 Reference Scenario (of a declining demand for labour between 2015 and 2030 followed by a moderate increase) is likely to be a result of the lack of new infrastructure investments. Overall, the employment associated with GFCF tends to fluctuate more while O&M employment depends on the employment factors of each electricity source and is thus more or less stable (depending on the energy mix). This is also reflected in the sectoral results: the 'winners' and 'losers' depend largely on whether labour demand for each respective year is dominated by GFCF or O&M. This is, in particular, the case under the Stanford WWS Scenario where typically industries with a strong link to capital formation (most significantly illustrated by construction and the manufacture of machinery and equipment n.e.c.) appear as the main 'winners' in the first phase only to drop back by 2050. In both scenarios, the main 'winners' are those electricity sectors with the largest representation in the energy mix. As a result, the overall effects in the long run depend rather on O&M employment factors whereas the massive labour demand wave related to capital investments creates relatively more, but only temporary, jobs. These findings are in accordance with Montt et al. (2018: 545) who conclude that (by 2030) '[t]he 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'.

Second, the difference between the two transition phases and O&M vs. GFCF jobs also has implications for educational policies and vocational training. Each of these sectors has a different structure of skills requirements, so the first issue is that timing needs to be taken into account. Additionally the biggest growth in labour demand is expected in high- and medium- skilled categories, suggesting that renewable energy sources generally require a more specialised workforce. Such findings are in accordance with Consoli et al. (2016) who state that green jobs are, in general, more intensive in terms of high-skilled labour. They are also in line with the projections presented in the JRC report: 'Different skill levels will benefit from different stages of the greening process. Initially higher-skilled roles are favoured (e.g. in technology research). As the green economy develops, demand will increase also for lower skilled labour' (Czako 2020: 37). Our analysis does not provide detailed results by O&M vs. GFCF jobs together with skill level so we cannot conclude from the data whether later phases of the transition may also require increased numbers of medium- to low-skilled workers, as the JRC report argues. This is an important topic for further research.

Supporting education and vocational training in related fields will be necessary in order to ensure that the transition is not held back by a shortage of sufficiently skilled labour. In other words, even though the Stanford WWS Scenario indicates much higher labour demand, whether labour materialises also depends on whether people with the required skills are available. So far, skills shortages seem to be a problem in areas other than the EU27+UK (Lucas et al. 2018) but are mentioned as a possible bottleneck in media publishing on the topic of the renewable energy transition.[18] However, this can change quickly if the transition is accelerated and curricula are not adapted in advance (or are not already being adapted) as training of sufficient quality also takes time. In this respect, science, technology, engineering and mathematics (STEM) skills are 'generally in high demand in the energy sector, and in the clean energy transition' (Czako 2020: 38). Among them, digital and computer knowledge, in particular, are not exclusively a requirement of high- and medium-skilled occupations (Czako 2020: 38) and it is clear that skill shortages of this type may also happen in supporting non-technical jobs as shown by Nasirov et al. (2021: 10) using the example of Chile: 'skill shortages were identified in non-technical occupations, such as legal advisors, sales specialists, inspectors, and economists, which are all critical for RE development'. This again corresponds to the JRC report which suggests that '[a] simultaneous shift in demand towards more multidisciplinary knowledge is also likely in the context of new business models and societal initiatives, including social enterprises' (Czako 2020: 37).

Third, the impacts on employment in industries other than electricity (especially service sectors) depend to a large extent on supply chains and the structure of international trade links. If no targeted measures are taken to change supply chains, the analysis suggests two impacts in particular for the EU27+UK region: a decline in the computer and related activities sector in the long term and an increase in wholesale and retail trade (see Figures 7, 8 and 9) both in the long and in the short term. These results may sound somewhat counter-intuitive as the usual assumption is that RES uptake is mutually reinforcing – or at least not mutually exclusive – with digitalisation (see Section 2.3). However, they may simply suggest that key parts of digital business related to renewables (unrelated to the capital investment behind the employment boom in this sector in the first phase) are allocated outside the EU27+UK while domestic wholesale and retail may also serve as an intermediary.

In summary, to avoid an imbalance between the skills on offer and those needed in the context of the renewable energy transition (specifically in electricity sectors), we propose up-skilling and re-skilling programmes not only in the renewable electricity generation sector, but also in other sectors that are linked to their supply chains to ensure that the transition to the post-carbon economy is not compromised.

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[18] Examples include:
https://energymonitor.ai/policy/just-transition/investment-in-skills-is-key-to-realising-the-clean-energy-transition
https://energymonitor.ai/policy/just-transition/why-equipping-workers-is-key-to-the-energy-transition
https://www.taylorhopkinson.com/wp-content/uploads/Skills-shortage-Report-Taylor-Hopkinson.pdf
https://www.euractiv.com/section/energy/news/skilled-workers-shortage-could-stall-germanys-progress-on-climate-targets/
https://www.switchtogreen.eu/the-green-employment-initiative/

Policies aimed at creating green jobs in the renewable energy sector should also take into account the growing controversy over continued economic growth and its climate impacts (see e.g. Hickel and Kallis 2020; Parrique et al. 2019). This would decouple the 'double dividend' of employment and GDP growth associated with renewable energy deployment which is usually, often even implicitly, assumed to be a desirable goal. While the large-scale investments needed to facilitate the transition and related infrastructure changes are perhaps likely to lead to further GDP growth, it is important to rethink the usual way these jobs are created to avoid further reinforcing the growth spiral (an outline of how to do this is provided, for example, by Hickel 2020) and also take into account some of the constraints that renewable energy-based job growth may actually pose to economic growth (see e.g. Kallis 2017).

5.3 Limitations

Most of the limitations result from the static nature of the IO model. However, it should be noted that the whole model is built more as a skeleton for integrating various kinds of external assumptions, of which we model only selected ones that describe the chosen scenarios (see our Introduction in Section 1). As such, the model allows us theoretically to include a number of other factors or variables.

First, the model works with constant returns to scale. Regarding for example labour intensity (where economies of scale may occur in the future, especially for technologies that are not yet widely in use such as electricity production from solar thermal or tidal and wave energy), such an assumption may lead to a certain overestimation of the job effects.

Second, we work with the assumption of fixed production technologies since this is an uncertain factor in the long run. Accounting for changes in technical coefficients would especially affect the indirect job effects because of the upstream linkages of electricity sectors with regard both to capital formation and to the requirements of intermediate inputs. Furthermore, factors such as changing legislation (RES support, etc.) can also be included in the model through different assumptions regarding production technology (specifically, for example, taxes or subsidies, or the total cost of electricity).

Third, as already mentioned, we do not model any changes in the proportions of different skill levels and gender nor changes in the trade structure and thus the geographical distribution of employment effects for any electricity sector. Whereas skill level proportions may, in general, be more 'predictable' by assuming certain learning curves for the modelled technologies, the other two items remain largely in the domains of political and economic choices. This is particularly relevant for international trade flows: if the EU decided to allocate more renewable energy production internally, the demand for labour in indirectly related sectors (see e.g. Figure 9) would grow much more domestically and might not create as much demand for labour abroad (see Figure 5). In considering the resulting employment effects, international trade linkages and associated geographical origin of employment play an important role. For example, if we have electricity sources that are mostly linked to domestic production (i.e. within the EU27+UK, in this case) and therefore domestic jobs, they are perhaps a convenient tool to foster domestic employment where this is the policy goal. Since we do not model any such fluctuations, the results should be understood again in the sense rather of what would happen if the current supply chains related to the electricity sectors in the EU27+UK remained unchanged.

Fourth, the inclusion of changes in electricity demand would allow for a more nuanced assessment to be modelled. However, this is beyond the scope of our analysis as this focuses solely on the production side (electricity supply) and does not track downstream flows (i.e. which sectors consume the supply of electricity).

Apart from these limitations of the IO framework, the model does not account for decommissioning jobs that could be particularly relevant for nuclear power (see e.g. Ram et al. 2020). Jobs related to decommissioning would probably arise in similar sectors as jobs related to capital formation (and would be very likely to accompany them in a similar phase of the transition), thereby giving a further boost to temporary employment linked to the restructuring of the electricity infrastructure. Furthermore, we do not take into account investments in storage and transmission systems that would certainly have to be accommodated in the case of a 100 per cent renewable energy transition. This would be likely to result in investments in the sectors referred to in EXIOBASE 3.6 as transmission of electricity and the distribution and trade of electricity and might be also implicitly present through the supply chains of capital investments in electricity sectors. This would further boost jobs related to the capital formation-dominated phase of the transition (assumingly until 2030-35 when the capital investments-intensive phase is assumed in the Stanford WWS Scenario to have concluded). However, both these factors could, at a later stage, be included within the input-output framework we present here.

6. Key conclusions

In a transition to 100 per cent renewable energy, the demand for labour in European electricity sectors could increase significantly. All except two of the investigated European countries would end up as net gainers in terms of jobs. This would be the case even in the absence of targeted policy measures aiming to shape the structure of the production supply chains related to renewable energy sources in favour of domestic production (i.e. even if their current structure is maintained). This qualifies renewable energy as a suitable instrument to support domestic job creation within the EU27+UK.

The most significant gains would materialise in the electricity sector together with retail and wholesale trade and the construction and manufacturing sectors. However, the surging employment effects in construction and manufacturing, for all their significance, would only be temporary and, after 2035, labour demand in these sectors would decline significantly. Given the different distribution of labour demand at sector level, we suggest that the two phases of the transition should be treated separately. The first phase is characteristic of high capital investments where it is crucial to ensure an adequate labour supply in construction and manufacturing. In the second phase, the overall 'new' demand for labour is driven more by the operation and maintenance activities of the respective electricity sectors. This will particularly affect the electricity sectors themselves and their upstream suppliers.

Furthermore, if the current structure of the skills required in each of the modelled electricity sectors is maintained, the transition will result in increased demand for high- and medium-skilled labour. We therefore suggest that greater attention be paid to related training and retraining activities in order to ensure an adequate labour supply for those sectors that will benefit most from the transition. At the same time, the skills and abilities of employees in declining industries should be taken into account. Ideally, the arising imbalances on the labour market, with an excess labour force in some sectors and a situation of additional demand in others, should be prevented or absorbed by appropriate measures in order to minimise the negative social impacts of restructuring the electricity sector towards 100 per cent renewables. The detailed results of this study, indicating which sectors could benefit or lose in which phase of the transition, possibly supplemented by an assessment of the skills and preferences of workers from the sectors at risk, can help to develop appropriate policy strategies for this purpose.

7. References

Ahola J. (2018) National survey report of PV power applications in Finland 2018, Paris, International Energy Agency.

Allan G.J. and Ross A.G. (2019) The characteristics of energy employment in a system-wide context, Energy Economics, 81, 238–258. https://doi.org/10.1016/j.eneco.2019.03.017

Almutairi K., Thoma G. and Durand-Morat A. (2018) Ex-ante analysis of economic, social and environmental impacts of large-scale renewable and nuclear energy targets for global electricity generation by 2030, Sustainability, 10 (8), 2884. https://doi.org/10.3390/su10082884

Bellini E. (2017) PV in Slovakia is kept alive by residential segment, pv magazine, 21 March 2017. https://www.pv-magazine.com/2017/03/21/pv-in-slovakia-is-kept-alive-by-residential-segment/.

Bernardo G. and D'Alessandro S. (2016) Systems-dynamic analysis of employment and inequality impacts of low-carbon investments, Environmental Innovation and Societal Transitions, 21, 123–144. https://doi.org/10.1016/j.eist.2016.04.006

Billman L. and Keyser D. (2013) Assessment of the value, impact, and validity of the jobs and economic development impacts (JEDI) Suite of Models (No. NREL/TP-6A20-56390, 1090964). https://doi.org/10.2172/1090964

Blanco M.I. and Rodrigues G. (2009) Direct employment in the wind energy sector: an EU study, Energy Policy, 37 (8), 2847–2857. https://doi.org/10.1016/j.enpol.2009.02.049

Böhringer C., Keller A. and van der Werf E. (2013) Are green hopes too rosy? Employment and welfare impacts of renewable energy promotion, Energy Economics, 36, 277–285. https://doi.org/10.1016/j.eneco.2012.08.029

Böhringer C. and Rutherford T.F. (2013) Transition towards a low carbon economy: a computable general equilibrium analysis for Poland, Energy Policy, 55, 16–26. https://doi.org/10.1016/j.enpol.2012.11.056

Bulavskaya T. and Reynès F. (2018) Job creation and economic impact of renewable energy in the Netherlands, Renewable Energy, 119, 528–538. https://doi.org/10.1016/j.renene.2017.09.039

Cai W., Mu Y., Wang C. and Chen J. (2014) Distributional employment impacts of renewable and new energy–A case study of China, Renewable and Sustainable Energy Reviews, 39, 1155–1163. https://doi.org/10.1016/j.rser.2014.07.136

Caldés N., Varela M., Santamaría M. and Sáez R. (2009) Economic impact of solar thermal electricity deployment in Spain, Energy Policy, 37 (5), 1628–1636. https://doi.org/10.1016/j.enpol.2008.12.022

Cambridge Econometrics (2013) Employment effects of selected scenarios from the Energy roadmap 2050, Cambridge, Cambridge Econometrics.

Cameron L. and van der Zwaan B. (2015) Employment factors for wind and solar energy technologies: a literature review, Renewable and Sustainable Energy Reviews, 45, 160–172. https://doi.org/10.1016/j.rser.2015.01.001

Capros P., De Vita A., Tasios N., Siskos P., Kannavou M., Petropoulos A., Evangelopoulou S., Zampara M., Papadopoulos D. and Nakos C. (2016) EU Reference Scenario 2016 - Energy, transport and GHG emissions trends to 2050, Luxembourg, Publications Office of the European Union.

Carlsson J., Lacal Arantegui R., Jäger-Waldau A., Vellei M., Sigfusson B., Magagna D., Jakubcionis M., Fortes M., Lazarou S., Giuntoli J., Weidner E., Marco G., Spisto A. and Moles C. (2014) Energy Technology Reference Indicator (ETRI) projections for 2010-2050, Luxembourg, Publications Office of the European Union. https://doi.org/10.2790/057687

Carlsson J. and Vellei M. (2014) 2013 Technology map of the European strategic energy technology plan (SET-Plan) - Technology descriptions, Luxembourg, Publications Office of the European Union.

Cella G. (1984) The input-output measurement of interindustry linkages, Oxford Bulletin of Economics and Statistics, 46 (1), 73–84. https://doi.org/10.1111/j.1468-0084.1984.mp46001005.x

Clancy J. and Roehr U. (2003) Gender and energy: is there a Northern perspective?, Energy for Sustainable Development, 7 (3), 44–49. https://doi.org/10.1016/S0973-0826(08)60364-6

Comodi G., Cioccolanti L., Mahkamov K., Penlington R., Lapuerta M., Hernandez J.J., Silva Lora E.E., Venturin, O., Melian Cobas V.R., Escobar Palacio J.C., Mendonça Freires F.G., Torres E.A., da Silva J.A.M., Kafarov V., Chacon Velasco J.L., Solano Martinez J.E., Lizarazo Salcedo G.Y., Serna Suárez I.D., Jaen R.L., Gonzalez J.I., Fernandez M., Garcia Faure L.J., Oliva-Merencio D., Reyes I.P., Salas J.M. and Ramírez C.C. (2019) Analysis of labour market needs for engineers with enhanced knowledge in renewable energy in some European and Latin-American countries, Energy Procedia, 158, 1135–1140. https://doi.org/10.1016/j.egypro.2019.01.279

Consoli D., Marin G., Marzucchi A. and Vona F. (2016) Do green jobs differ from non-green jobs in terms of skills and human capital?, Research Policy, 45 (5), 1046–1060. https://doi.org/10.1016/j.respol.2016.02.007

Conti J., Holtberg P., Diefenderfer J., LaRose A., Turnure J.T. and Westfall L. (2016) International energy outlook 2016 with projections to 2040, Washington, DC, U.S. Energy Information Administration.. https://doi.org/10.2172/1296780

Countryeconomy.com (n.d) Malta - Electricity generation 2019 Malta - Electricity generation. https://countryeconomy.com/energy-and-environmen/electricity-generation/malta

Cyprus Energy Regulatory Authority (2021) State of electricity production from solar PV systems, biomass/biogas units and wind parks connected to the network.

Czako V. (2020) Employment in the energy sector: status report 2020, Luxembourg, Publications Office of the European Union.

Dalton G.J. and Lewis T. (2011) Metrics for measuring job creation by renewable energy technologies, using Ireland as a case study, Renewable and Sustainable Energy Reviews, 15 (4), 2123–2133. https://doi.org/10.1016/j.rser.2011.01.015

Dell'Anna F. (2021) Green jobs and energy efficiency as strategies for economic growth and the reduction of environmental impacts, Energy Policy, 149, 112031. https://doi.org/10.1016/j.enpol.2020.112031

Deschenes O. (2015) Green jobs, in Wright J.D. (ed.) International encyclopedia of the social & behavioral sciences (2nd ed.), Oxford, Elsevier, 372–378. https://doi.org/10.1016/B978-0-08-097086-8.94025-X

Duscha V., Fougeyrollas A., Nathani C., Pfaff M., Ragwitz M., Resch G., Schade W., Breitschopf B. and Walz R. (2016) Renewable energy deployment in Europe up to 2030 and the aim of a triple dividend, Energy Policy, 95, 314–323. https://doi.org/10.1016/j.enpol.2016.05.011

Duscha V., Ragwitz M., Breitschopf B., Schade W., Walz R., Pfaff M., De Visser E., Resch G., Nathani C. and Zagamé P. (2014) Employment and growth effects of sustainable energies in the European Union, Brussels, European Commission.

Dvořák P., Martinát S., der Horst D.V., Frantál B., Turečková K. (2017) Renewable energy investment and job creation; a cross-sectoral assessment for the Czech Republic with reference to EU benchmarks, Renewable and Sustainable Energy Reviews, 69, 360–368. https://doi.org/10.1016/j.rser.2016.11.158

EIA (2018) Annual energy outlook 2018 with projections to 2050, Washington, DC, U.S. Energy Information Administration.

ENTSO-E (2021) Power Statistics.

European Commission (2018) Final report of the high-level panel of the European decarbonisation pathways initiative, Luxembourg, Publications Office of the European Union.

European Commission (2021) Employment and social developments in Europe 2021. Towards a strong social Europe in the aftermath of the COVID 19 crisis: reducing disparities and addressing distributional impacts, Luxembourg, Publications Office of the European Union.

European Investment Bank (2021) EIB investment report 2020/2021: building a smart and green Europe in the COVID 19 era, Luxembourg, Publications Office of the European Union.

Eurostat (1996) NACE Rev. 1: Statistical classification of economic activities in the European Community. http://op.europa.eu/en/publication-detail/-/publication/212c93fc-53ca-437f-827d-b91a61908145/language-en

Eurostat (2021a) Electricity production capacities by main fuel groups and operator (nrg_inf_epc).

Eurostat (2021b) Electricity production capacities for renewables and wastes (nrg_inf_epcrw).

Eurostat (2021c) Gross and net production of electricity and derived heat by type of plant and operator (nrg_ind_peh).

Eurostat (2021d) Gross production of electricity and derived heat from non-combustible fuels by type of plant and operator (nrg_ind_pehnf).

EWEA (2012) Green growth - The impact of wind energy on jobs and the economy, Brussels, European Wind Energy Association.

Fragkos P. and Paroussos L. (2018) Employment creation in EU related to renewables expansion, Applied Energy, 230, 935–945. https://doi.org/10.1016/j.apenergy.2018.09.032

Füllemann Y., Moreau V., Vielle M. and Vuille F. (2020) Hire fast, fire slow: the employment benefits of energy transitions, Economic Systems Research, 32, 202–220. https://doi.org/10.1080/09535314.2019.1695584

Garrett-Peltier H. (2017) Green versus brown: comparing the employment impacts of energy efficiency, renewable energy, and fossil fuels using an input-output model, Economic Modelling, 61, 439–447. https://doi.org/10.1016/j.econmod.2016.11.012

Geels F.W., Berkhout F. and Van Vuuren D.P. (2016) Bridging analytical approaches for low-carbon transitions, Nature Climate Change, 6, 576–583. http://dx.doi.org/10.1038/nclimate2980

Geels F.W., Sovacool B.K., Schwanen T. and Sorrell S. (2017) Sociotechnical transitions for deep decarbonization. Science, 357, 1242–1244. https://doi.org/10.1126/science.aao3760

Goddard G. and Farrelly M.A. (2018) Just transition management: Balancing just outcomes with just processes in Australian renewable energy transitions, Applied Energy, 225, 110–123. https://doi.org/10.1016/j.apenergy.2018.05.025

Hickel J. (2020) Degrowth and MMT: a thought experiment, 23 September 2020. https://www.jasonhickel.org/blog/2020/9/10/degrowth-and-mmt-a-thought-experiment

Hickel J. and Kallis G. (2020) Is green growth possible?, New Political Economy, 25 (4), 469–486. https://doi.org/10.1080/13563467.2019.1598964

Hoegh-Guldberg O., Jacob D., Taylor M., Bolaños T.G., Bindi M., Brown S., Camilloni I.A., Diedhiou A., Djalante R., Ebi K., Engelbrecht F., Guiot J., Hijioka Y., Mehrotra S., Hope C.W., Payne A.J., Pörtner H.-O., Seneviratne S.I., Thomas A., Warren R. and Zhou G. (2019) The human imperative of stabilizing global climate change at 1.5°C, Science, 365 (6459). https://doi.org/10.1126/science.aaw6974

IRENA (2017) Renewable energy and jobs - Annual Review 2017, Abu Dhabi, International Renewable Energy Agency.

IRENA (2019) Renewable power generation costs in 2019, Abu Dhabi, International Renewable Energy Agency.

IRENA (2020) Renewable energy and jobs - Annual Review 2020, Abu Dhabi, International Renewable Energy Agency.

Jacobson M.Z., Delucchi M.A., Bauer Z.A.F., Goodman S.C., Chapman W.E., Cameron M.A., Bozonnat C., Chobadi L., Clonts H.A., Enevoldsen P., Erwin J.R., Fobi S.N., Goldstrom O.K., Hennessy E.M., Liu J., Lo J., Meyer C.B., Morris S.B., Moy K.R., O'Neill P.L., Petkov I., Redfern S., Schucker R., Sontag M.A., Wang J., Weiner E. and Yachanin A.S. (2017) 100% clean and renewable wind, water, and sunlight all-sector energy roadmaps for 139 countries of the world, Joule, 1 (1), 108–121. https://doi.org/10.1016/j.joule.2017.07.005

Jacobson M.Z., Delucchi M.A., Cameron M.A., Coughlin S.J., Hay C.A., Manogaran I.P., Shu Y. and Krauland A.K. (2019) Spreadsheets for 143-country, 24-world region WWS study.

Jacobson M.Z., Delucchi M.A., Cameron M.A., Coughlin S.J., Hay C.A., Manogaran I.P., Shu Y. and von Krauland A.K. (2019) Impacts of Green New Deal energy plans on grid stability, costs, jobs, health, and climate in 143 countries, One Earth, 1 (4), 449–463. https://doi.org/10.1016/j.oneear.2019.12.003

Jasanoff S. (2018) Just transitions: a humble approach to global energy futures, Energy Research & Social Science, 35, 11–14. https://doi.org/10.1016/j.erss.2017.11.025

Jenkins K., Sovacool B.K. and McCauley D. (2018) Humanizing sociotechnical transitions through energy justice: an ethical framework for global transformative change, Energy Policy, 117, 66–74. https://doi.org/10.1016/j.enpol.2018.02.036

Jenniches S. (2018) Assessing the regional economic impacts of renewable energy sources – A literature review. Renewable and Sustainable Energy Reviews, 93, 35–51. https://doi.org/10.1016/j.rser.2018.05.008

Kamidelivand M., Cahill C., Llop M., Rogan F. and O'Gallachoir B. (2018) A comparative analysis of substituting imported gas and coal for electricity with renewables – An input-output simulation, Sustainable Energy Technologies and Assessments, 30, 1–10. https://doi.org/10.1016/j.seta.2018.08.003

Keček D., Mikulić D. and Lovrinčević Ž. (2019) Deployment of renewable energy: economic effects on the Croatian economy, Energy Policy, 126, 402–410. https://doi.org/10.1016/j.enpol.2018.11.028

Kendziorski M., Zozmann E. and Kunz F. (2020) National generation capacity. https://doi.org/10.25832/NATIONAL_GENERATION_CAPACITY/2020-10-01

Kerschner C. and Hubacek K. (2009) Assessing the suitability of input–output analysis for enhancing our understanding of potential economic effects of peak oil, 34 (3), 284–290. https://doi.org/10.1016/j.energy.2008.07.009

Köhler J., Geels F.W., Kern F., Markard J., Onsongo E., Wieczorek A., Alkemade F., Avelino F., Bergek A., Boons F., Fünfschilling L., Hess D., Holtz G., Hyysal, S., Jenkins K., Kivimaa P., Martiskainen M., McMeekin A., Mühlemeier M.S., Nykvist B., Pel B., Raven R., Rohracher H., Sandén B., Schot J., Sovacool B., Turnheim B., Welch D. and Wells P. (2019) An agenda for sustainability transitions research: state of the art and future directions, Environmental Innovation and Societal Transitions, 31, 1–32. https://doi.org/10.1016/j.eist.2019.01.004

Lambert R.J. and Silva P.P (2012) The challenges of determining the employment effects of renewable energy, Renewable and Sustainable Energy Reviews, 16 (7), 4667–4674. https://doi.org/10.1016/j.rser.2012.03.072

Lehr U., Lutz C. and Edler D. (2012) Green jobs? Economic impacts of renewable energy in Germany, Energy Policy, 47, 358–364. https://doi.org/10.1016/j.enpol.2012.04.076

Lehr U., Nitsch J., Kratzat M., Lutz C. and Edler D. (2008) Renewable energy and employment in Germany, Energy Policy, 36 (1), 108–117. https://doi.org/10.1016/j.enpol.2007.09.004

Lettner G., Auer H., Fleischhacker A., Schwabeneder D., Dallinger B., Moisl F., Roman E., Velte D. and Huidobro A. (2018) Existing and future PV prosumer concepts. https://www.pvp4grid.eu/wp-content/uploads/2018/08/D2.1_Existing-future-prosumer-concepts_PVP4Grid_FV.pdf

Lewney R., Alexandri E., Storrie D.W. and Pérez J.I.A. (2019) Energy scenario: employment implications of the Paris climate agreement, Luxembourg, Publications Office of the European Union.

Llera E., Scarpellini S., Aranda A. and Zabalza I. (2013) Forecasting job creation from renewable energy deployment through a value-chain approach, Renewable and Sustainable Energy Reviews, 21, 262–271. https://doi.org/10.1016/j.rser.2012.12.053

Lucas H., Pinnington S. and Cabeza L.F. (2018) Education and training gaps in the renewable energy sector, Solar Energy, 173, 449–455. https://doi.org/10.1016/j.solener.2018.07.061

Markaki M., Belegri-Roboli A., Michaelides P., Mirasgedis S. and Lalas D.P. (2013) The impact of clean energy investments on the Greek economy: an input–output analysis (2010–2020), Energy Policy, 57, 263–275. https://doi.org/10.1016/j.enpol.2013.01.047

Markandya A., Arto I., González-Eguino M. and Román M.V. (2016) Towards a green energy economy? Tracking the employment effects of low-carbon technologies in the European Union, Applied Energy, 179, 1342–1350. https://doi.org/10.1016/j.apenergy.2016.02.122

Markkanen S. and Anger-Kraavi A. (2019) Social impacts of climate change mitigation policies and their implications for inequality, Climate Policy, 19 (7), 827-844. https://doi.org/10.1080/14693062.2019.1596873

McCauley D. and Heffron R. (2018) Just transition: integrating climate, energy and environmental justice, Energy Policy, 119, 1–7. https://doi.org/10.1016/j.enpol.2018.04.014

Miller R.E. and Blair P.D. (2009) Input-output analysis: foundations and extensions, Cambridge, Cambridge University Press.

Montt G., Wiebe K.S., Harsdorff M., Simas M., Bonnet A. and Wood R. (2018) Does climate action destroy jobs? An assessment of the employment implications of the 2-degree goal, International Labour Review, 157 (4), 519–556. https://doi.org/10.1111/ilr.12118

Moreno B. and López A.J. (2008) The effect of renewable energy on employment. The case of Asturias (Spain), Renewable and Sustainable Energy Reviews, 12 (3), 732–751. https://doi.org/10.1016/j.rser.2006.10.011

Nasirov S., Girard A., Peña C., Salazar F. and Simon F. (2021) Expansion of renewable energy in Chile: analysis of the effects on employment, Energy, 226, 120410. https://doi.org/10.1016/j.energy.2021.120410

Oliveira C., Coelho D., Pereira da Silva P. and Antunes C.H. (2013) How many jobs can the RES-E sectors generate in the Portuguese context?, Renewable and Sustainable Energy Reviews, 21, 444–455. https://doi.org/10.1016/j.rser.2013.01.011

Ortega M., del Río P., Ruiz P., Thiel C. (2015) Employment effects of renewable electricity deployment. A novel methodology, Energy, 91, 940–951. https://doi.org/10.1016/j.energy.2015.08.061

Ortega M., del Río P., Ruiz P., Nijs W. and Politis S. (2020) Analysing the influence of trade, technology learning and policy on the employment prospects of wind and solar energy deployment: the EU case, Renewable and Sustainable Energy Reviews, 122, 109657. https://doi.org/10.1016/j.rser.2019.109657

Parrique T., Barth J., Briens F., Kerschner C., Kraus-Polk A., Kuokkanen A. and Spangenberg J.H (2019) Decoupling debunked. Evidence and arguments against green growth as a sole strategy for sustainability, Brussels, The European Environmental Bureau.

Peters G. and Solli C. (2010) Global carbon footprints: methods and import/export corrected results from the Nordic countries in global carbon footprint studies, Copenhagen, Nordic Council of Ministers.

Ragwitz M., Schade W., Breitschopf B., Walz R., Helfrich N., Rathmann M., Resch G., Panzer C., Faber T., Haas R., Nathani C., Holzhey M., Konstantinaviciute I., Zagame P., Fougeyrollas A. and Le Hir B. (2009) EmployRES. The impact of renewable energy policy on economic growth and employment in the European Union. Final report.

Ram M., Aghahosseini A. and Breyer C. (2020) Job creation during the global energy transition towards 100% renewable power system by 2050, Technological Forecasting and Social Change, 151, 119682. https://doi.org/10.1016/j.techfore.2019.06.008

Rodríguez-Huerta E., Rosas-Casals M. and Sorman A.H. (2017) A societal metabolism approach to job creation and renewable energy transitions in Catalonia, Energy Policy, 108, 551–564. https://doi.org/10.1016/j.enpol.2017.06.024

Rutovitz J., Dominish E. and Downes J. (2015) Calculating global energy sector jobs: 2015 methodology update.

Rutovitz J. and Harris S. (2012) Calculating global energy sector jobs: methodology, Sydney, Institute for Sustainable Futures.

Ryan S.E. (2014) Rethinking gender and identity in energy studies, Energy Research & Social Science, 1, 96–105. https://doi.org/10.1016/j.erss.2014.02.008

Schlecht I. and Simic M. (2020) Renewable power plants. https://doi.org/10.25832/RENEWABLE_POWER_PLANTS/2020-08-25

SolarPower Europe (2015) Solar photovoltaics jobs & value added in Europe.

Sooriyaarachchi T.M., Tsai I.-T., El Khatib S., Farid A.M., Mezher T. (2015) Job creation potentials and skill requirements in, PV, CSP, wind, water-to-energy and energy efficiency value chains, Renewable and Sustainable Energy Reviews, 52, 653–668. https://doi.org/10.1016/j.rser.2015.07.143

Stadler K., Wood R., Bulavskaya T., Södersten C.-J., Simas M., Schmidt S., Usubiaga A., Acosta Fernández J., Kuenen J., Bruckner M., Giljum S., Lutter S., Merciai S., Schmidt J.H., Theurl M.C., Plutzar C., Kastner T., Eisenmenger N., Erb K.-H., Koning A. de and Tukker A. (2018) EXIOBASE 3: developing a time series of detailed environmentally extended multi-regional input-output tables, Journal of Industrial Ecology, 22 (3), 502–515. https://doi.org/10.1111/jiec.12715

Stavropoulos S. and Burger M.J. (2020) Modelling strategy and net employment effects of renewable energy and energy efficiency: a meta-regression, Energy Policy, 136, 111047. https://doi.org/10.1016/j.enpol.2019.111047

Steininger K.W. and Voraberger H. (2003) Exploiting the medium term biomass energy potentials in Austria - A comparison of costs and macroeconomic impact, Environmental and Resource Economics, 24, 359–377. https://doi.org/10.1023/A:1023680125027

Teske S., Sawyer S., Schäfer O., Pregger T., Simon S., Naegler T., Schmid S., Özdemir E.D., Pagenkopf J. and Kleiner F. (2015) Energy [r]evolution - a sustainable world energy outlook 2015, Amsterdam, Greenpeace international.

Toshkin M. (n.d) Case study of Bulgaria: PV Market Overview.

Tourkoliass C. and Mirasgedis S. (2011) Quantification and monetization of employment benefits associated with renewable energy technologies in Greece, Renewable and Sustainable Energy Reviews, 15 (6), 2876–2886. https://doi.org/10.1016/j.rser.2011.02.027

Wasiuta A. (2018) Labor market in Poland in the context of renewable energy sector development, Ekonomia i Środowisko, 1.

Zekaria Y. and Chitchyan R. (2019) Literature review of skill shortage assessment models. https://doi.org/10.13140/RG.2.2.28731.13605

All links were checked on 10.11.2021.

8. Supplementary materials

8.1 Input-output analysis – derivation of the Leontief matrix

To construct the so-called total requirements matrix to find a unique solution to the set of n linear equations in the n unknowns from $x_1, x_2, \ldots x_n$, we have first to define identity matrix I with 1s on the main diagonal and zeros in all other places:

Equation 13

$$I = \begin{bmatrix} 1 & \ldots & 0 \\ \vdots & \ddots & \vdots \\ 0 & \ldots & 1 \end{bmatrix}$$

The Leontief matrix is then constructed as:

Equation 14

$$(I - A) = \begin{bmatrix} (1 - a_{11}) & \ldots & -a_{1n} \\ \vdots & \ddots & \vdots \\ -a_{n1} & \ldots & (1 - a_{nn}) \end{bmatrix}$$

Which means, in the $n \times n$ matrix representation, combined with Eq. 4 in Section 3.1:

Equation 15

$$(I - A)x = f$$

The unique solution to the set of equations can be found if $(I–A)^{-1}$ exists, i.e. whether $(I–A) \neq 0$. $(I–A)^{-1}$ is called the Leontief inverse (L). The calculation of L is as follows:

Equation 16

$$L = (I - A)^{-1}$$

Finally, output x can be denoted as:

Equation 17

$$x = (I - A)^{-1} f = Lf$$

8.2 GFCF data operations

8.2.1 Construction of the detailed GFCF columns

To assemble the respective k_{il}^t columns for each modelled electricity sector l, we first calculate the difference in total installed capacity between individual years. Since installed capacity is given in the scenarios for every five years, we assume that the relevant capital investments will be evenly distributed over each five-year period.

Equation 18

$$\Delta c_l^t = \frac{c_t - c_{(t-1)}}{5} \text{ for } \Delta c_l^t \geq 0$$

Δc_l^t indicates how much capacity needs to be installed in the five-year period before t so that the given source can cover the required electricity production according to the modelled scenario. We convert these numbers (given in MW) into millions of 2015 Euros by multiplying them by the costs of installed capacity for each source of electricity and country (denoting them as p_l^t as for the price in the given year) given in million Euros per MW (see the datasheet available as supplementary information[19]). With this, we obtain the GFCF k_l^t for each modelled sector l in each given year t:

Equation 19

$$k_l^t = p_l^t * \Delta c_l^t$$

Then we use the concordance matrix (see Table 4) to distribute k_l^t to the 165 sectors of the model, resulting in t matrices with the dimension $165 \times l$, i.e. not distinguishing country of origin. We spread the values for each of the 165 sectors to the originating countries according to each country's share in the supply of the respective sector to GFCF in the original data of EXIOBASE (from the F matrix). For example, assume that the wind power sector in country A has a total investment of 10 million Euros into the outputs of the construction sector and that the original GFCF column in EXIOBASE shows that countries A, B, and C contribute 50 per cent, 30 per cent and 20 per cent respectively to country A's GFCF in construction services. The 10 million Euros will thus be split between these countries accordingly, i.e. 5, 3 and 2 million Euros will be attributed to the construction sectors of countries A, B and C respectively. This yields the detailed GFCF columns k_{il}^t that allow an analysis of the GFCF-related employment effects, as explained in Section 3.3.5.

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[19] GFCF.xlsx

Table 4 **Concordance matrix matching the capex breakdown for each electricity generation technology according to the ETRI 2014 report with the EXIOBASE 3.6 industries**

Source	Category	EXIOBASE 3.6 industry	Share
Coal	Civil and structural costs	Construction (45)	11.0%
	Mechanical equipment supply and installation costs	Manufacture of machinery and equipment n.e.c. (29)	40.0%
	Electrical and I&C supply and installation	Manufacture of electrical machinery and apparatus n.e.c. (31)	6.0%
	Project indirect costs	Financial intermediation, except insurance and pension funding (65)	6.5%
		Activities auxiliary to financial intermediation (67)	6.5%
		Computer and related activities (72)	6.5%
		Other business activities (74)	6.5%
	Owner’s costs	Construction (45)	4.3%
		Insurance and pension funding, except compulsory social security (66)	4.3%
		Real estate activities (70)	4.3%
		Computer and related activities (72)	4.3%
Gas	Civil and structural costs	Construction (45)	4.0%
	Mechanical equipment supply and installation costs	Manufacture of machinery and equipment n.e.c. (29)	46.0%
	Electrical and I&C supply and installation	Manufacture of electrical machinery and apparatus n.e.c. (31)	6.0%
	Project indirect costs	Financial intermediation, except insurance and pension funding (65)	7.5%
		Activities auxiliary to financial intermediation (67)	7.5%
		Computer and related activities (72)	7.5%
		Other business activities (74)	7.5%
	Owner’s costs	Construction (45)	3.5%
		Insurance and pension funding, except compulsory social security (66)	3.5%
		Real estate activities (70)	3.5%
		Computer and related activities (72)	3.5%
Nuclear	Civil and structural costs	Construction (45)	15.0%
	Mechanical equipment supply and installation costs	Manufacture of machinery and equipment n.e.c. (29)	28.0%
	Electrical and I&C supply and installation	Manufacture of electrical machinery and apparatus n.e.c. (31)	5.0%
	Project indirect costs	Financial intermediation, except insurance and pension funding (65)	8.5%
		Activities auxiliary to financial intermediation (67)	8.5%
		Computer and related activities (72)	8.5%
		Other business activities (74)	8.5%
	Owner’s costs	Construction (45)	4.5%
		Insurance and pension funding, except compulsory social security (66)	4.5%
		Real estate activities (70)	4.5%
		Computer and related activities (72)	4.5%
Hydro	Civil and structural costs	Construction (45)	30.0%
	Mechanical equipment supply and installation costs	Manufacture of machinery and equipment n.e.c. (29)	33.0%
	Electrical and I&C supply and installation	Manufacture of electrical machinery and apparatus n.e.c. (31)	4.0%
	Project indirect costs	Financial intermediation, except insurance and pension funding (65)	2.3%
		Activities auxiliary to financial intermediation (67)	2.3%
		Computer and related activities (72)	2.3%
		Other business activities (74)	2.3%

Source	Category	EXIOBASE 3.6 industry	Share
Hydro	Owner's costs	Construction (45)	6.0%
		Insurance and pension funding, except compulsory social security (66)	6.0%
		Real estate activities (70)	6.0%
		Computer and related activities (72)	6.0%
Onshore wind	Civil and structural costs	Construction (45)	12.0%
	Mechanical equipment supply and installation costs	Manufacture of machinery and equipment n.e.c. (29)	65.0%
	Electrical and I&C supply and installation	Manufacture of electrical machinery and apparatus n.e.c. (31)	15.0%
	Project indirect costs	Financial intermediation, except insurance and pension funding (65)	1.3%
		Activities auxiliary to financial intermediation (67)	1.3%
		Computer and related activities (72)	1.3%
		Other business activities (74)	1.3%
		Insurance and pension funding, except compulsory social security (66)	1.3%
		Real estate activities (70)	1.3%
Offshore wind	Civil and structural costs	Construction (45)	18.0%
	Mechanical equipment supply and installation costs	Manufacture of machinery and equipment n.e.c. (29)	51.0%
	Electrical and I&C supply and installation	Manufacture of electrical machinery and apparatus n.e.c. (31)	9.0%
	Project indirect costs	Financial intermediation, except insurance and pension funding (65)	4.4%
		Activities auxiliary to financial intermediation (67)	4.4%
		Computer and related activities (72)	4.4%
		Other business activities (74)	4.4%
		Insurance and pension funding, except compulsory social security (66)	4.4%
Petroleum and oil	Civil and structural costs	Construction (45)	3.0%
	Mechanical equipment supply and installation costs	Manufacture of machinery and equipment n.e.c. (29)	46.0%
	Electrical and I&C supply and installation	Manufacture of electrical machinery and apparatus n.e.c. (31)	9.0%
	Project indirect costs	Financial intermediation, except insurance and pension funding (65)	6.0%
		Activities auxiliary to financial intermediation (67)	6.0%
		Computer and related activities (72)	6.0%
		Other business activities (74)	6.0%
	Owner's costs	Construction (45)	4.5%
		Insurance and pension funding, except compulsory social security (66)	4.5%
		Real estate activities (70)	4.5%
		Computer and related activities (72)	4.5%
Bioenergy	Civil and structural costs	Construction (45)	16.0%
	Mechanical equipment supply and installation costs	Manufacture of machinery and equipment n.e.c. (29)	63.0%
	Electrical and I&C supply and installation	Manufacture of electrical machinery and apparatus n.e.c. (31)	8.0%
	Project indirect costs	Financial intermediation, except insurance and pension funding (65)	1.0%
		Activities auxiliary to financial intermediation (67)	1.0%
		Computer and related activities (72)	1.0%
		Other business activities (74)	1.0%
	Owner's costs	Construction (45)	2.3%
		Insurance and pension funding, except compulsory social security (66)	2.3%
		Real estate activities (70)	2.3%
		Computer and related activities (72)	2.3%

Source	Category	EXIOBASE 3.6 industry	Share
Utility solar PV	Civil and structural costs	Construction (45)	17.0%
	Mechanical equipment supply and installation costs	Manufacture of machinery and equipment n.e.c. (29)	45.0%
	Electrical and I&C supply and installation	Manufacture of electrical machinery and apparatus n.e.c. (31)	10.0%
	Project indirect costs	Financial intermediation, except insurance and pension funding (65)	4.5%
		Activities auxiliary to financial intermediation (67)	4.5%
		Computer and related activities (72)	4.5%
		Other business activities (74)	4.5%
	Owner's costs	Construction (45)	2.5%
		Insurance and pension funding, except compulsory social security (66)	2.5%
		Real estate activities (70)	2.5%
		Computer and related activities (72)	2.5%
Residential solar PV	Civil and structural costs	Construction (45)	17.0%
	Mechanical equipment supply and installation costs	Manufacture of machinery and equipment n.e.c. (29)	45.0%
	Electrical and I&C supply and installation	Manufacture of electrical machinery and apparatus n.e.c. (31)	10.0%
	Project indirect costs	Financial intermediation, except insurance and pension funding (65)	4.5%
		Activities auxiliary to financial intermediation (67)	4.5%
		Computer and related activities (72)	4.5%
		Other business activities (74)	4.5%
	Owner's costs	Construction (45)	3.3%
		Insurance and pension funding, except compulsory social security (66)	3.3%
		Computer and related activities (72)	3.3%
Solar thermal (CSP)	Civil and structural costs	Construction (45)	58.0%
	Mechanical equipment supply and installation costs	Manufacture of machinery and equipment n.e.c. (29)	8.0%
	Electrical and I&C supply and installation	Manufacture of electrical machinery and apparatus n.e.c. (31)	8.0%
	Project indirect costs	Financial intermediation, except insurance and pension funding (65)	4.0%
		Activities auxiliary to financial intermediation (67)	4.0%
		Computer and related activities (72)	4.0%
		Other business activities (74)	4.0%
	Owner's costs	Construction (45)	2.5%
		Insurance and pension funding, except compulsory social security (66)	2.5%
		Real estate activities (70)	2.5%
		Computer and related activities (72)	2.5%
Tide, wave, ocean	Civil and structural costs	Construction (45)	38.0%
	Mechanical equipment supply and installation costs	Manufacture of machinery and equipment n.e.c. (29)	42.0%
	Electrical and I&C supply and installation	Manufacture of electrical machinery and apparatus n.e.c. (31)	8.0%
	Project indirect costs	Financial intermediation, except insurance and pension funding (65)	1.8%
		Activities auxiliary to financial intermediation (67)	1.8%
		Computer and related activities (72)	1.8%
		Other business activities (74)	1.8%
	Owner's costs	Construction (45)	1.3%
		Insurance and pension funding, except compulsory social security (66)	1.3%
		Real estate activities (70)	1.3%
		Computer and related activities (72)	1.3%

Source	Category	EXIOBASE 3.6 industry	Share
Geothermal	Civil and structural costs	Construction (45)	5.0%
	Mechanical equipment supply and installation costs	Manufacture of machinery and equipment n.e.c. (29)	51.0%
	Electrical and I&C supply and installation	Manufacture of electrical machinery and apparatus n.e.c. (31)	7.0%
	Project indirect costs	Financial intermediation, except insurance and pension funding (65)	4.0%
		Activities auxiliary to financial intermediation (67)	4.0%
		Computer and related activities (72)	4.0%
		Other business activities (74)	4.0%
	Owner's costs	Construction (45)	5.3%
		Insurance and pension funding, except compulsory social security (66)	5.3%
		Real estate activities (70)	5.3%
		Computer and related activities (72)	5.3%

Source: Carlsson et al. (2014); own elaboration using NACE rev. 1 industry description (Publications Office of the European Union 1996)

8.2.2 Installed capacity costs: country-to-country replacements

To replace the missing values of costs per MW of installed capacity we used data from Germany for Austria, Belgium,[20] Czech Republic, Denmark, Luxembourg, Poland and Slovakia; data from Italy for Bulgaria, Cyprus, Greece, Croatia, Malta and Slovenia; data from Sweden (onshore and offshore wind) and from the United Kingdom (solar PV) for Estonia, Finland, Lithuania and Latvia; data from Italy (onshore and offshore wind) and from France (solar PV) for Hungary and Romania; data from the United Kingdom for Ireland; data for Germany (onshore wind and solar PV) and from Belgium (offshore wind) for the Netherlands; data for Spain for Portugal; and, finally, data from the United Kingdom for Sweden. Furthermore, data from Greece were used to replace values for coal in Cyprus; data from Finland were used to replace values for coal in Estonia, Lithuania, Latvia and Sweden; data from Belgium to replace values for coal in Luxembourg; and data from Italy for coal in Malta.

8.3 Technical coefficients and employment intensities: country-to-country replacements

We replaced the following missing columns of technical coefficients (part of A) and/or employment intensity (part of M) in the electricity sectors accordingly:

- **Austria**: Nuclear - Czechia; Offshore wind - Germany; Solar thermal - Spain; Tide, wave, ocean - France
- **Belgium**: Solar thermal - Spain; Tide, wave, ocean - France; Geothermal - Austria

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[20] Except for offshore wind where country-specific data were available.

- **Bulgaria**: Offshore wind - Portugal; Solar thermal - Spain; Tide, wave, ocean - France; Geothermal - Italy
- **Cyprus**: Coal - Greece; Gas - Greece; Nuclear - Bulgaria; Hydro - Greece; Offshore wind - Portugal; Solar thermal - Spain; Tide, wave, ocean - France; Geothermal - Italy
- **Czechia**: Offshore wind - Germany; Biomass and waste - Slovakia;[21] Solar thermal - Spain; Tide, wave, ocean - France; Geothermal - Austria
- **Germany**: Solar thermal - Spain; Tide, wave, ocean - France
- **Denmark**: Nuclear - Sweden; Solar thermal - Spain; Tide, wave, ocean - France; Geothermal - Austria
- **Estonia**: Nuclear - Sweden; Offshore wind - Germany; Utility solar PV - Sweden; Residential solar PV - Finland; Solar thermal - Spain; Tide, wave, ocean - France; Geothermal - Austria
- **Spain**: Offshore wind - Portugal; Tide, wave, ocean - France; Geothermal - Portugal
- **Finland**: Utility solar PV - Sweden; Solar thermal - Spain; Tide, wave, ocean - France; Geothermal - Austria
- **France**: Offshore wind - Portugal; Solar thermal - Spain; Geothermal - Italy
- **Greece**: Nuclear - Bulgaria; Offshore wind - Portugal; Solar thermal - Spain; Tide, wave, ocean - France; Geothermal - Italy
- **Croatia**: Nuclear - Bulgaria; Offshore wind - Portugal; Utility solar PV - Italy; Residential solar PV - Italy; Solar thermal - Spain; Tide, wave, ocean - France; Geothermal - Italy
- **Hungary**: Offshore wind - Germany; Solar thermal - Spain; Tide, wave, ocean - France; Geothermal - Austria
- **Ireland**: Nuclear - United Kingdom; Offshore wind - United Kingdom; Utility solar PV - United Kingdom; Residential solar PV - United Kingdom; Solar thermal - Spain; Tide, wave, ocean - France; Geothermal - Austria
- **Italy**: Nuclear - France; Offshore wind - Portugal; Solar thermal - Spain; Tide, wave, ocean - France
- **Lithuania**: Coal - Estonia; Nuclear - Sweden; Offshore wind - Germany; Utility solar PV - Sweden; Residential solar PV - Finland; Solar thermal - Spain; Tide, wave, ocean - France; Geothermal - Austria
- **Luxembourg**: Coal - Germany; Nuclear - Germany; Offshore wind - Germany; Utility solar PV - Germany; Solar thermal - Spain; Tide, wave, ocean - France; Geothermal - Austria
- **Latvia**: Nuclear - Sweden; Offshore wind - Germany; Petroleum and oil - Estonia; Utility solar PV - Sweden; Residential solar PV - Finland; Solar thermal - Spain; Tide, wave, ocean - France; Geothermal - Austria
- **Malta**: Coal - Italy; Gas - Italy; Nuclear - France; Hydro - Italy; Onshore wind - Italy; Offshore wind - Portugal; Utility solar PV - Italy; Residential solar PV - Italy; Solar thermal - Spain; Tide, wave, ocean - France; Geothermal - Italy
- **Netherlands**: Coal - Germany; Nuclear - Germany; Offshore wind - Germany; Solar thermal - Spain; Tide, wave, ocean - France; Geothermal - Austria

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[21] Employment intensity only.

- **Poland**: Nuclear - Germany; Offshore wind - Germany; Utility solar PV - Czechia; Residential solar PV - Czechia; Solar thermal - Spain; Tide, wave, ocean - France; Geothermal - Austria
- **Portugal**: Nuclear - Spain; Solar thermal - Spain; Tide, wave, ocean - France
- **Romania**: Offshore wind - Portugal; Residential solar PV - Hungary; Solar thermal - Spain; Tide, wave, ocean - France; Geothermal - Italy
- **Sweden**: Solar thermal - Spain; Tide, wave, ocean - France; Geothermal - Austria
- **Slovenia**: Onshore wind - Italy; Offshore wind - Portugal; Residential solar PV - Austria; Solar thermal - Spain; Tide, wave, ocean - France; Geothermal - Italy
- **Slovakia**: Offshore wind - Germany; Solar thermal - Spain; Tide, wave, ocean - France; Geothermal - Austria
- **United Kingdom**: Solar thermal - Spain; Tide, wave, ocean - France; Geothermal - Austria

8.4 Detailed results

8.4.1 Tables

Table 5 **Employment effects related to changes in the energy mix in electricity production in the EU27+UK by operation and maintenance vs. capital formation (domestic vs. rest of the world)**

Employment effects by operation and maintenance vs. capital formation			Employment total - employed persons (000)							
Scenario	Origin	Effect	2015	2020	2025	2030	2035	2040	2045	2050
Stanford	Domestic (EU27+UK)	O&M	1687.0	2477.2	3660.1	4843.0	5138.7	5434.5	5533.1	5631.6
Stanford	Domestic (EU27+UK)	GFCF	1942.3	4088.3	5951.7	6221.6	3315.6	3318.4	2666.8	2606.6
Stanford	Rest of the world	O&M	1554.3	1747.9	2037.8	2327.7	2400.2	2472.6	2496.8	2520.9
Stanford	Rest of the world	GFCF	2275.7	5000.1	7350.4	7715.7	4098.2	4107.3	3294.4	3218.3
EU Reference	Domestic (EU27+UK)	O&M	1687.0	1847.9	1949.5	1987.5	2165.2	2364.8	2419.1	2457.2
EU Reference	Domestic (EU27+UK)	GFCF	1942.3	**1403.0**	**1004.8**	**1099.6**	**892.8**	**1035.6**	**1170.6**	**1277.1**
EU Reference	Rest of the world	O&M	1554.3	1602.3	1678.6	1672.0	1823.0	1994.8	1963.9	1909.3
EU Reference	Rest of the world	GFCF	2275.7	**1880.7**	**1140.0**	**1223.8**	**987.3**	**1195.2**	**1353.7**	**1491.3**
			Change in employment compared to 2015 (%)							
Stanford	Domestic (EU27+UK)	O&M		47%	117%	187%	205%	222%	228%	234%
Stanford	Domestic (EU27+UK)	GFCF		110%	206%	220%	71%	71%	37%	34%
Stanford	Rest of the world	O&M		12%	31%	50%	54%	59%	61%	62%
Stanford	Rest of the world	GFCF		120%	223%	239%	80%	80%	45%	41%
EU Reference	Domestic (EU27+UK)	O&M		10%	16%	18%	28%	40%	43%	46%
EU Reference	Domestic (EU27+UK)	GFCF		**-28%**	**-48%**	**-43%**	**-54%**	**-47%**	**-40%**	**-34%**
EU Reference	Rest of the world	O&M		3%	8%	8%	17%	28%	26%	23%
EU Reference	Rest of the world	GFCF		**-17%**	**-50%**	**-46%**	**-57%**	**-47%**	**-41%**	**-34%**

Table 6 **Employment effects related to changes in the energy mix in electricity production in the EU27+UK and abroad triggered by expenditure in the EU27+UK**

Employment effects in the EU27+UK and abroad triggered by expenditure in the EU27+UK			Employment total - employed persons (000)							
Scenario	Origin	Region (destination)	2015	2020	2025	2030	2035	2040	2045	2050
Stanford	Domestic (EU27+UK)	Africa	598.7	1032.6	1413.0	1525.1	1052.1	1068.6	964.4	959.5
Stanford	Domestic (EU27+UK)	Asia	2211.8	4066.7	5751.2	6184.9	3958.6	4014.9	3520.2	3489.1
Stanford	Domestic (EU27+UK)	Australia	11.3	19.4	27.3	30.1	21.4	21.9	20.0	20.0
Stanford	Domestic (EU27+UK)	EU27+UK	3629.4	6565.4	9611.8	11064.6	8454.4	8752.9	8199.9	8238.2
Stanford	Domestic (EU27+UK)	Latin America	146.9	243.2	331.7	358.7	250.8	255.1	231.3	230.3
Stanford	Domestic (EU27+UK)	Middle East	85.4	154.5	215.0	226.6	138.9	140.0	120.4	118.8
Stanford	Domestic (EU27+UK)	North America	159.1	248.1	325.1	338.4	223.1	223.8	198.0	195.7
Stanford	Domestic (EU27+UK)	Rest of Europe	616.9	983.4	1324.8	1379.5	853.4	855.7	736.9	725.9
EU Reference	Domestic (EU27+UK)	Africa	598.7	603.0	**517.2**	**534.0**	**544.4**	632.3	662.9	668.9
EU Reference	Domestic (EU27+UK)	Asia	2211.8	**2035.0**	**1579.5**	**1628.8**	**1553.6**	**1761.3**	**1851.7**	**1911.7**
EU Reference	Domestic (EU27+UK)	Australia	11.3	**10.0**	**8.9**	**9.2**	**9.2**	**10.2**	**10.5**	**10.7**
EU Reference	Domestic (EU27+UK)	EU27+UK	3629.4	**3250.9**	**2954.3**	**3087.0**	**3058.0**	**3400.3**	**3589.7**	3734.2
EU Reference	Domestic (EU27+UK)	Latin America	146.9	**127.9**	**104.7**	**104.6**	**101.5**	**113.8**	**116.7**	**117.7**
EU Reference	Domestic (EU27+UK)	Middle East	85.4	**75.9**	**61.9**	**63.7**	**62.3**	**70.5**	**72.6**	**74.3**
EU Reference	Domestic (EU27+UK)	North America	159.1	**144.0**	**109.2**	**109.7**	**102.3**	**107.0**	**109.6**	**112.3**
EU Reference	Domestic (EU27+UK)	Rest of Europe	616.9	**487.3**	**437.2**	**445.8**	**436.9**	**495.0**	**493.6**	**505.0**
			Change in employment compared to 2015 (%)							
Stanford	Domestic (EU27+UK)	Africa		72%	136%	155%	76%	78%	61%	60%
Stanford	Domestic (EU27+UK)	Asia		84%	160%	180%	79%	82%	59%	58%
Stanford	Domestic (EU27+UK)	Australia		72%	141%	166%	89%	94%	77%	77%
Stanford	Domestic (EU27+UK)	EU27+UK		81%	165%	205%	133%	141%	126%	127%
Stanford	Domestic (EU27+UK)	Latin America		66%	126%	144%	71%	74%	57%	57%
Stanford	Domestic (EU27+UK)	Middle East		81%	152%	165%	63%	64%	41%	39%
Stanford	Domestic (EU27+UK)	North America		56%	104%	113%	40%	41%	24%	23%
Stanford	Domestic (EU27+UK)	Rest of Europe		59%	115%	124%	38%	39%	19%	18%
EU Reference	Domestic (EU27+UK)	Africa		1%	**-14%**	**-11%**	**-9%**	6%	11%	12%
EU Reference	Domestic (EU27+UK)	Asia		**-8%**	**-29%**	**-26%**	**-30%**	**-20%**	**-16%**	**-14%**
EU Reference	Domestic (EU27+UK)	Australia		**-12%**	**-21%**	**-19%**	**-19%**	**-10%**	**-7%**	**-6%**
EU Reference	Domestic (EU27+UK)	EU27+UK		**-10%**	**-19%**	**-15%**	**-16%**	**-6%**	**-1%**	3%
EU Reference	Domestic (EU27+UK)	Latin America		**-13%**	**-29%**	**-29%**	**-31%**	**-23%**	**-21%**	**-20%**
EU Reference	Domestic (EU27+UK)	Middle East		**-11%**	**-28%**	**-25%**	**-27%**	**-17%**	**-15%**	**-13%**
EU Reference	Domestic (EU27+UK)	North America		**-9%**	**-31%**	**-31%**	**-36%**	**-33%**	**-31%**	**-29%**
EU Reference	Domestic (EU27+UK)	Rest of Europe		**-21%**	**-29%**	**-28%**	**-29%**	**-20%**	**-20%**	**-18%**

Table 7 **Employment effects related to changes in the energy mix in electricity production in the EU27+UK by skill level and gender (domestic)**

Employment effects by skill level and gender			Employment total - employed persons (000)							
Scenario	Origin	Skill level and gender	2015	2020	2025	2030	2035	2040	2045	2050
Stanford	Domestic (EU27+UK)	High-skilled male	893.7	1645.6	2477.7	2939.7	2366.0	2466.9	2349.1	2368.5
Stanford	Domestic (EU27+UK)	Medium-skilled male	1311.8	2503.8	3697.2	4256.6	3210.8	3323.3	3101.5	3114.8
Stanford	Domestic (EU27+UK)	Low-skilled male	173.0	316.0	455.0	512.2	373.4	384.3	354.4	354.9
Stanford	Domestic (EU27+UK)	High-skilled female	492.1	828.8	1196.4	1367.9	1046.0	1081.7	1013.2	1017.6
Stanford	Domestic (EU27+UK)	Medium-skilled female	622.4	1041.6	1460.8	1627.8	1198.7	1230.4	1137.4	1138.2
Stanford	Domestic (EU27+UK)	Low-skilled female	136.4	229.7	324.6	360.5	259.4	266.2	244.2	244.2
EU Reference	Domestic (EU27+UK)	High-skilled male	893.7	808.5	729.0	768.6	763.4	854.7	905.9	947.3
EU Reference	Domestic (EU27+UK)	Medium-skilled male	1311.8	1193.9	1079.1	1124.2	1106.4	1227.8	1302.8	1361.1
EU Reference	Domestic (EU27+UK)	Low-skilled male	173.0	153.9	142.2	148.7	144.8	160.2	169.9	176.2
EU Reference	Domestic (EU27+UK)	High-skilled female	492.1	419.6	389.5	411.2	411.0	457.0	477.6	492.8
EU Reference	Domestic (EU27+UK)	Medium-skilled female	622.4	559.8	509.2	524.5	523.4	582.6	610.9	630.1
EU Reference	Domestic (EU27+UK)	Low-skilled female	136.4	115.1	105.4	109.8	109.0	118.1	122.7	126.7
			Change in employment compared to 2015 (%)							
Stanford	Domestic (EU27+UK)	High-skilled male		84%	177%	229%	165%	176%	163%	165%
Stanford	Domestic (EU27+UK)	Medium-skilled male		91%	182%	224%	145%	153%	136%	137%
Stanford	Domestic (EU27+UK)	Low-skilled male		83%	163%	196%	116%	122%	105%	105%
Stanford	Domestic (EU27+UK)	High-skilled female		68%	143%	178%	113%	120%	106%	107%
Stanford	Domestic (EU27+UK)	Medium-skilled female		67%	135%	162%	93%	98%	83%	83%
Stanford	Domestic (EU27+UK)	Low-skilled female		68%	138%	164%	90%	95%	79%	79%
EU Reference	Domestic (EU27+UK)	High-skilled male		-10%	-18%	-14%	-15%	-4%	1%	6%
EU Reference	Domestic (EU27+UK)	Medium-skilled male		-9%	-18%	-14%	-16%	-6%	-1%	4%
EU Reference	Domestic (EU27+UK)	Low-skilled male		-11%	-18%	-14%	-16%	-7%	-2%	2%
EU Reference	Domestic (EU27+UK)	High-skilled female		-15%	-21%	-16%	-16%	-7%	-3%	0%
EU Reference	Domestic (EU27+UK)	Medium-skilled female		-10%	-18%	-16%	-16%	-6%	-2%	1%
EU Reference	Domestic (EU27+UK)	Low-skilled female		-16%	-23%	-19%	-20%	-13%	-10%	-7%

Table 8 **Employment effects related to changes in the energy mix in electricity production in the EU27+UK by sector – the 10 sectors with the most significant increase vs. the 10 sectors with the most significant decrease (domestic; sorted by 2050 values)**

Employment effects by sector – the 10 sectors with the most significant increase vs. the 10 sectors with the most significant decrease (sorted by 2050 values)			Change in employment compared to 2015 (employed persons, 000)						
Scenario	Destination	Sector	2020	2025	2030	2035	2040	2045	2050
Stanford	Domestic (EU27+UK)	Production of electricity by residential solar photovoltaic	370.7	925.0	1479.3	1617.9	1756.5	1802.7	1848.8
Stanford	Domestic (EU27+UK)	Production of electricity by utility solar photovoltaic	331.3	828.2	1325.2	1449.4	1573.6	1615.0	1656.5
Stanford	Domestic (EU27+UK)	Production of electricity by onshore wind	74.8	186.9	299.1	327.1	355.2	364.5	373.8
Stanford	Domestic (EU27+UK)	Production of electricity by offshore wind	134.6	267.2	323.6	194.8	205.8	178.0	178.6
Stanford	Domestic (EU27+UK)	Retail trade, except motor vehicles and motorcycles; repair of personal and household goods (52)	400.0	712.6	762.2	289.2	289.2	185.2	176.5
Stanford	Domestic (EU27+UK)	Wholesale trade and commission trade, except motor vehicles and motorcycles (51)	460.1	859.8	925.2	309.2	310.9	171.8	158.5
Stanford	Domestic (EU27+UK)	Production of electricity by solar thermal	137.1	265.4	309.5	162.6	170.1	137.9	137.1
Stanford	Domestic (EU27+UK)	Production of electricity by tide, wave, ocean	19.6	49.1	78.6	85.9	93.3	95.8	98.2
Stanford	Domestic (EU27+UK)	Incineration of waste: metals and inert materials	116.4	212.1	227.2	79.1	79.6	46.1	43.0
Stanford	Domestic (EU27+UK)	Real estate activities (70)	86.0	156.1	166.0	54.9	54.8	29.7	27.2
Stanford	Domestic (EU27+UK)	Supporting and auxiliary transport activities; activities of travel agencies (63)	-1.5	-3.8	-6.1	-6.7	-7.3	-7.4	-7.6
Stanford	Domestic (EU27+UK)	Manufacture of gas; distribution of gaseous fuels through mains	-0.3	-1.3	-3.7	-6.9	-7.6	-8.4	-8.6
Stanford	Domestic (EU27+UK)	Manufacture of fabricated metal products, except machinery and equipment (28)	21.1	35.6	30.5	-7.4	-9.5	-18.3	-19.7
Stanford	Domestic (EU27+UK)	Manufacture of electrical machinery and apparatus n.e.c. (31)	156.5	328.1	339.8	49.2	47.3	-18.0	-24.4
Stanford	Domestic (EU27+UK)	Activities auxiliary to financial intermediation (67)	-4.9	-12.4	-19.8	-21.6	-23.5	-24.1	-24.7
Stanford	Domestic (EU27+UK)	Production of electricity by nuclear	-6.1	-15.4	-24.6	-26.9	-29.2	-30.0	-30.7
Stanford	Domestic (EU27+UK)	Construction (45)	-7.4	-18.7	-30.3	-33.7	-36.6	-37.6	-38.6
Stanford	Domestic (EU27+UK)	Other business activities (74)	-8.4	-21.0	-33.6	-36.8	-39.9	-41.0	-42.0
Stanford	Domestic (EU27+UK)	Computer and related activities (72)	-7.8	-20.2	-33.2	-37.7	-41.0	-42.4	-43.5
Stanford	Domestic (EU27+UK)	Manufacture of machinery and equipment n.e.c. (29)	-14.5	-36.4	-58.2	-63.6	-69.1	-70.9	-72.7

Employment effects by sector – the 10 sectors with the most significant increase vs. the 10 sectors with the most significant decrease (sorted by 2050 values)			Change in employment compared to 2015 (employed persons, 000)						
Scenario	Destination	Sector	2020	2025	2030	2035	2040	2045	2050
EU Reference	Domestic (EU27+UK)	Production of electricity by residential solar photovoltaic	370.7	925.0	1479.3	1617.9	1756.5	1802.7	1848.8
EU Reference	Domestic (EU27+UK)	Production of electricity by onshore wind	331.3	828.2	1325.2	1449.4	1573.6	1615.0	1656.5
EU Reference	Domestic (EU27+UK)	Production of electricity by biomass and waste	74.8	186.9	299.1	327.1	355.2	364.5	373.8
EU Reference	Domestic (EU27+UK)	Production of electricity by utility solar photovoltaic	134.6	267.2	323.6	194.8	205.8	178.0	178.6
EU Reference	Domestic (EU27+UK)	Production of electricity by gas	400.0	712.6	762.2	289.2	289.2	185.2	176.5
EU Reference	Domestic (EU27+UK)	Production of electricity by solar thermal	460.1	859.8	925.2	309.2	310.9	171.8	158.5
EU Reference	Domestic (EU27+UK)	Forestry, logging and related service activities (02)	137.1	265.4	309.5	162.6	170.1	137.9	137.1
EU Reference	Domestic (EU27+UK)	Manufacture of gas; distribution of gaseous fuels through mains	19.6	49.1	78.6	85.9	93.3	95.8	98.2
EU Reference	Domestic (EU27+UK)	Supporting and auxiliary transport activities; activities of travel agencies (63)	116.4	212.1	227.2	79.1	79.6	46.1	43.0
EU Reference	Domestic (EU27+UK)	Production of electricity by offshore wind	86.0	156.1	166.0	54.9	54.8	29.7	27.2
EU Reference	Domestic (EU27+UK)	Wholesale trade and commission trade, except motor vehicles and motorcycles (51)	-1.5	-3.8	-6.1	-6.7	-7.3	-7.4	-7.6
EU Reference	Domestic (EU27+UK)	Mining of coal and lignite; extraction of peat (10)	-0.3	-1.3	-3.7	-6.9	-7.6	-8.4	-8.6
EU Reference	Domestic (EU27+UK)	Financial intermediation, except insurance and pension funding (65)	21.1	35.6	30.5	-7.4	-9.5	-18.3	-19.7
EU Reference	Domestic (EU27+UK)	Manufacture of fabricated metal products, except machinery and equipment (28)	156.5	328.1	339.8	49.2	47.3	-18.0	-24.4
EU Reference	Domestic (EU27+UK)	Manufacture of electrical machinery and apparatus n.e.c. (31)	-4.9	-12.4	-19.8	-21.6	-23.5	-24.1	-24.7
EU Reference	Domestic (EU27+UK)	Activities auxiliary to financial intermediation (67)	-6.1	-15.4	-24.6	-26.9	-29.2	-30.0	-30.7
EU Reference	Domestic (EU27+UK)	Other business activities (74)	-7.4	-18.7	-30.3	-33.7	-36.6	-37.6	-38.6
EU Reference	Domestic (EU27+UK)	Construction (45)	-8.4	-21.0	-33.6	-36.8	-39.9	-41.0	-42.0
EU Reference	Domestic (EU27+UK)	Computer and related activities (72)	-7.8	-20.2	-33.2	-37.7	-41.0	-42.4	-43.5
EU Reference	Domestic (EU27+UK)	Manufacture of machinery and equipment n.e.c. (29)	-14.5	-36.4	-58.2	-63.6	-69.1	-70.9	-72.7

Table 9 Employment effects related to changes in the energy mix in electricity production in the EU27+UK by electricity source (domestic vs. rest of the world)

Employment effects by electricity source			Employment total - employed persons (000)							
Scenario	Destination	Electricity source	2015	2020	2025	2030	2035	2040	2045	2050
Stanford	Domestic (EU27+UK)	Geothermal	5.6	12.8	18.8	22.4	18.6	19.4	18.5	18.6
Stanford	Domestic (EU27+UK)	Tide, wave, ocean	1.8	124.3	204.6	236.0	156.6	147.5	137.9	137.8
Stanford	Domestic (EU27+UK)	Solar thermal	7.3	63.2	98.7	111.2	73.6	76.5	69.2	70.3
Stanford	Domestic (EU27+UK)	Residential solar PV	270.7	1578.8	2792.6	3569.8	2921.6	3104.2	2978.8	3026.6
Stanford	Domestic (EU27+UK)	Utility solar PV	149.2	1076.1	1974.0	2574.8	2248.7	2397.3	2336.4	2370.7
Stanford	Domestic (EU27+UK)	Biomass and waste	308.6	**112.3**	**69.4**	**27.4**	**17.0**	**6.7**	**3.3**	**0.0**
Stanford	Domestic (EU27+UK)	Petroleum and other oil derivatives	367.7	**84.7**	**52.9**	**21.2**	**13.2**	**5.3**	**2.6**	**0.0**
Stanford	Domestic (EU27+UK)	Offshore wind	206.8	849.9	1354.0	1497.3	885.7	916.0	782.6	780.5
Stanford	Domestic (EU27+UK)	Onshore wind	410.8	1315.2	2138.3	2534.3	1759.4	1829.3	1656.0	1655.4
Stanford	Domestic (EU27+UK)	Hydro	208.9	**158.6**	**166.5**	**174.1**	**175.2**	**177.1**	**177.5**	**178.2**
Stanford	Domestic (EU27+UK)	Nuclear	350.6	**272.4**	**168.7**	**66.9**	**41.3**	**16.4**	**8.2**	**0.0**
Stanford	Domestic (EU27+UK)	Gas	769.9	**505.4**	**315.9**	**126.4**	**79.0**	**31.6**	**15.8**	**0.0**
Stanford	Domestic (EU27+UK)	Coal	571.5	**411.8**	**257.4**	**102.9**	**64.3**	**25.7**	**12.9**	**0.0**
Stanford	Rest of the world	Geothermal	7.9	19.4	31.2	40.6	38.1	40.3	39.9	40.5
Stanford	Rest of the world	Tide, wave, ocean	1.4	128.6	198.9	212.1	113.5	97.0	84.0	81.9
Stanford	Rest of the world	Solar thermal	3.5	33.2	49.7	53.0	30.3	30.9	26.4	26.7
Stanford	Rest of the world	Residential solar PV	210.7	1174.0	1896.6	2172.3	1379.1	1436.0	1264.4	1270.1
Stanford	Rest of the world	Utility solar PV	163.1	1067.9	1830.7	2224.6	1731.8	1828.3	1723.5	1736.9
Stanford	Rest of the world	Biomass and waste	414.6	**143.3**	**88.5**	**35.0**	**21.6**	**8.6**	**4.2**	**0.0**
Stanford	Rest of the world	Petroleum and other oil derivatives	480.3	**127.3**	**79.6**	**31.8**	**19.9**	**8.0**	**4.0**	**0.0**
Stanford	Rest of the world	Offshore wind	242.1	1124.8	1755.5	1891.8	1038.2	1064.6	876.7	868.8
Stanford	Rest of the world	Onshore wind	518.6	1651.6	2614.9	2973.6	1826.7	1875.3	1613.1	1595.4
Stanford	Rest of the world	Hydro	147.0	**109.2**	**113.5**	**117.4**	**117.6**	**118.6**	**118.8**	**119.1**
Stanford	Rest of the world	Nuclear	239.0	**183.6**	**113.4**	**44.8**	**27.6**	**10.9**	**5.4**	**0.0**
Stanford	Rest of the world	Gas	753.8	**509.7**	**318.5**	**127.4**	**79.6**	**31.9**	**15.9**	**0.0**
Stanford	Rest of the world	Coal	648.2	**475.5**	**297.2**	**118.9**	**74.3**	**29.7**	**14.9**	**0.0**
EU Reference	Domestic (EU27+UK)	Geothermal	5.6	12.3	10.3	10.4	10.5	10.9	10.4	10.2
EU Reference	Domestic (EU27+UK)	Tide, wave, ocean	1.8	6.0	6.2	9.1	12.3	15.6	17.2	15.4
EU Reference	Domestic (EU27+UK)	Solar thermal	7.3	16.6	37.8	48.4	50.0	54.3	40.2	64.4
EU Reference	Domestic (EU27+UK)	Residential solar PV	270.7	360.1	344.3	368.6	349.1	402.6	547.8	642.7
EU Reference	Domestic (EU27+UK)	Utility solar PV	149.2	**119.5**	**101.5**	**113.7**	**99.9**	**121.5**	154.5	176.0
EU Reference	Domestic (EU27+UK)	Biomass and waste	308.6	328.8	**215.1**	**229.7**	**243.1**	**299.5**	322.5	311.0
EU Reference	Domestic (EU27+UK)	Petroleum and other oil derivatives	367.7	**62.6**	**118.1**	**117.0**	**100.6**	**77.8**	**72.8**	**46.8**
EU Reference	Domestic (EU27+UK)	Offshore wind	206.8	**125.9**	**45.5**	**46.8**	**39.2**	**45.5**	**61.0**	**61.9**
EU Reference	Domestic (EU27+UK)	Onshore wind	410.8	484.4	**409.1**	453.4	**353.1**	458.7	553.8	653.4
EU Reference	Domestic (EU27+UK)	Hydro	208.9	**186.4**	**166.2**	**171.7**	**173.6**	**178.7**	**188.7**	**191.2**
EU Reference	Domestic (EU27+UK)	Nuclear	350.6	**349.7**	**343.8**	439.4	392.2	365.2	357.5	**338.5**
EU Reference	Domestic (EU27+UK)	Gas	769.9	**722.1**	770.1	**754.5**	990.9	1191.8	1135.0	1028.2
EU Reference	Domestic (EU27+UK)	Coal	571.5	**476.4**	**386.3**	**324.3**	**243.5**	**178.1**	**128.3**	**194.5**
EU Reference	Rest of the world	Geothermal	7.9	32.3	30.5	30.6	30.8	31.6	31.0	30.7
EU Reference	Rest of the world	Tide, wave, ocean	1.4	5.9	5.3	7.4	9.3	10.6	10.3	7.8

Employment effects by electricity source			Employment total - employed persons (000)							
Scenario	Destination	Electricity source	2015	2020	2025	2030	2035	2040	2045	2050
EU Reference	Rest of the world	Solar thermal	3.5	8.8	20.4	25.4	25.2	26.5	17.8	30.8
EU Reference	Rest of the world	Residential solar PV	210.7	257.2	**191.4**	**184.5**	**154.6**	**190.9**	276.4	321.8
EU Reference	Rest of the world	Utility solar PV	163.1	**98.2**	**66.3**	**67.4**	**53.4**	**69.9**	**88.0**	**99.7**
EU Reference	Rest of the world	Biomass and waste	414.6	499.8	**304.4**	**322.1**	**356.0**	437.8	475.3	457.8
EU Reference	Rest of the world	Petroleum and other oil derivatives	480.3	**84.1**	**135.0**	**129.9**	**100.4**	**81.8**	**75.4**	**45.4**
EU Reference	Rest of the world	Offshore wind	242.1	**202.7**	**68.2**	**66.1**	**56.4**	**65.3**	**86.1**	**89.9**
EU Reference	Rest of the world	Onshore wind	518.6	679.3	**449.3**	**490.4**	**348.6**	**474.3**	580.4	688.1
EU Reference	Rest of the world	Hydro	147.0	**126.0**	**113.6**	**117.0**	**119.5**	**123.2**	**130.8**	**132.8**
EU Reference	Rest of the world	Nuclear	239.0	259.1	**235.4**	315.8	266.0	255.9	250.2	240.4
EU Reference	Rest of the world	Gas	753.8	**708.1**	790.2	800.1	1027.3	1239.0	1173.1	1083.1
EU Reference	Rest of the world	Coal	648.2	**521.3**	**408.6**	**339.0**	**262.8**	**183.0**	**122.7**	**172.3**
			Change in employment compared to 2015 (%)							
Stanford	Domestic (EU27+UK)	Geothermal		128%	234%	298%	231%	244%	230%	231%
Stanford	Domestic (EU27+UK)	Tide, wave, ocean		6937%	11487%	13265%	8767%	8251%	7712%	7706%
Stanford	Domestic (EU27+UK)	Solar thermal		770%	1259%	1431%	914%	954%	854%	868%
Stanford	Domestic (EU27+UK)	Residential solar PV		483%	932%	1219%	979%	1047%	1001%	1018%
Stanford	Domestic (EU27+UK)	Utility solar PV		621%	1223%	1626%	1407%	1507%	1466%	1489%
Stanford	Domestic (EU27+UK)	Biomass and waste		**-64%**	**-78%**	**-91%**	**-95%**	**-98%**	**-99%**	**-100%**
Stanford	Domestic (EU27+UK)	Petroleum and other oil derivatives		**-77%**	**-86%**	**-94%**	**-96%**	**-99%**	**-99%**	**-100%**
Stanford	Domestic (EU27+UK)	Offshore wind		311%	555%	624%	328%	343%	278%	277%
Stanford	Domestic (EU27+UK)	Onshore wind		220%	421%	517%	328%	345%	303%	303%
Stanford	Domestic (EU27+UK)	Hydro		**-24%**	**-20%**	**-17%**	**-16%**	**-15%**	**-15%**	**-15%**
Stanford	Domestic (EU27+UK)	Nuclear		**-22%**	**-52%**	**-81%**	**-88%**	**-95%**	**-98%**	**-100%**
Stanford	Domestic (EU27+UK)	Gas		**-34%**	**-59%**	**-84%**	**-90%**	**-96%**	**-98%**	**-100%**
Stanford	Domestic (EU27+UK)	Coal		**-28%**	**-55%**	**-82%**	**-89%**	**-95%**	**-98%**	**-100%**
Stanford	Rest of the world	Geothermal		146%	297%	417%	385%	412%	407%	415%
Stanford	Rest of the world	Tide, wave, ocean		9232%	14329%	15285%	8135%	6939%	5991%	5841%
Stanford	Rest of the world	Solar thermal		853%	1329%	1422%	769%	789%	659%	666%
Stanford	Rest of the world	Residential solar PV		457%	800%	931%	555%	582%	500%	503%
Stanford	Rest of the world	Utility solar PV		555%	1023%	1264%	962%	1021%	957%	965%
Stanford	Rest of the world	Biomass and waste		**-65%**	**-79%**	**-92%**	**-95%**	**-98%**	**-99%**	**-100%**
Stanford	Rest of the world	Petroleum and other oil derivatives		**-73%**	**-83%**	**-93%**	**-96%**	**-98%**	**-99%**	**-100%**
Stanford	Rest of the world	Offshore wind		365%	625%	681%	329%	340%	262%	259%
Stanford	Rest of the world	Onshore wind		219%	404%	473%	252%	262%	211%	208%
Stanford	Rest of the world	Hydro		**-26%**	**-23%**	**-20%**	**-20%**	**-19%**	**-19%**	**-19%**
Stanford	Rest of the world	Nuclear		**-23%**	**-53%**	**-81%**	**-88%**	**-95%**	**-98%**	**-100%**
Stanford	Rest of the world	Gas		**-32%**	**-58%**	**-83%**	**-89%**	**-96%**	**-98%**	**-100%**
Stanford	Rest of the world	Coal		**-27%**	**-54%**	**-82%**	**-89%**	**-95%**	**-98%**	**-100%**
EU Reference	Domestic (EU27+UK)	Geothermal		119%	83%	85%	87%	94%	86%	81%
EU Reference	Domestic (EU27+UK)	Tide, wave, ocean		241%	253%	414%	594%	786%	873%	772%
EU Reference	Domestic (EU27+UK)	Solar thermal		129%	421%	567%	589%	648%	453%	787%
EU Reference	Domestic (EU27+UK)	Residential solar PV		33%	27%	36%	29%	49%	102%	137%
EU Reference	Domestic (EU27+UK)	Utility solar PV		**-20%**	**-32%**	**-24%**	**-33%**	**-19%**	4%	18%
EU Reference	Domestic (EU27+UK)	Biomass and waste		7%	**-30%**	**-26%**	**-21%**	**-3%**	4%	1%

Employment effects by electricity source			Change in employment compared to 2015 (%)							
Scenario	Destination	Electricity source	2015	2020	2025	2030	2035	2040	2045	2050
EU Reference	Domestic (EU27+UK)	Petroleum and other oil derivatives		-83%	-68%	-68%	-73%	-79%	-80%	-87%
EU Reference	Domestic (EU27+UK)	Offshore wind		-39%	-78%	-77%	-81%	-78%	-71%	-70%
EU Reference	Domestic (EU27+UK)	Onshore wind		18%	0%	10%	-14%	12%	35%	59%
EU Reference	Domestic (EU27+UK)	Hydro		-11%	-20%	-18%	-17%	-14%	-10%	-8%
EU Reference	Domestic (EU27+UK)	Nuclear		0%	-2%	25%	12%	4%	2%	-3%
EU Reference	Domestic (EU27+UK)	Gas		-6%	0%	-2%	29%	55%	47%	34%
EU Reference	Domestic (EU27+UK)	Coal		-17%	-32%	-43%	-57%	-69%	-78%	-66%
EU Reference	Rest of the world	Geothermal		311%	288%	289%	291%	302%	294%	290%
EU Reference	Rest of the world	Tide, wave, ocean		331%	288%	440%	573%	666%	647%	465%
EU Reference	Rest of the world	Solar thermal		152%	486%	629%	623%	662%	410%	786%
EU Reference	Rest of the world	Residential solar PV		22%	-9%	-12%	-27%	-9%	31%	53%
EU Reference	Rest of the world	Utility solar PV		-40%	-59%	-59%	-67%	-57%	-46%	-39%
EU Reference	Rest of the world	Biomass and waste		21%	-27%	-22%	-14%	6%	15%	10%
EU Reference	Rest of the world	Petroleum and other oil derivatives		-82%	-72%	-73%	-79%	-83%	-84%	-91%
EU Reference	Rest of the world	Offshore wind		-16%	-72%	-73%	-77%	-73%	-64%	-63%
EU Reference	Rest of the world	Onshore wind		31%	-13%	-5%	-33%	-9%	12%	33%
EU Reference	Rest of the world	Hydro		-14%	-23%	-20%	-19%	-16%	-11%	-10%
EU Reference	Rest of the world	Nuclear		8%	-1%	32%	11%	7%	5%	1%
EU Reference	Rest of the world	Gas		-6%	5%	6%	36%	64%	56%	44%
EU Reference	Rest of the world	Coal		-20%	-37%	-48%	-59%	-72%	-81%	-73%

Table 10 **Employment effects related to changes in the energy mix in electricity production in the EU27+UK by country (domestic; relative increase/decrease compared to 2015 values**

Employment effects by country			Employment total - employed persons (000)							
Scenario	Origin	Country	2015	2020	2025	2030	2035	2040	2045	2050
Stanford	Domestic	Austria	63.9	124.4	186.5	219.4	172.9	180.1	170.3	171.4
Stanford	Domestic	Belgium	54.4	127.1	198.1	241.3	202.7	212.8	205.1	207.3
Stanford	Domestic	Bulgaria	43.2	142.5	217.3	245.7	164.5	170.0	152.3	152.3
Stanford	Domestic	Croatia	58.6	66.0	97.7	112.3	84.8	88.0	82.2	82.6
Stanford	Domestic	Cyprus	5.1	19.8	39.0	55.6	54.9	58.9	59.2	60.5
Stanford	Domestic	Czechia	97.9	205.3	297.8	334.7	239.6	246.7	225.8	225.8
Stanford	Domestic	Denmark	38.2	54.0	77.4	87.1	63.9	65.6	60.7	60.7
Stanford	Domestic	Estonia	26.1	30.4	53.7	72.3	68.0	72.5	72.0	73.3
Stanford	Domestic	Finland	64.0	87.4	136.8	162.0	123.3	128.8	120.5	121.4
Stanford	Domestic	France	360.5	686.6	979.2	1110.8	839.9	866.0	808.6	811.7
Stanford	Domestic	Germany	817.4	1335.6	1935.2	2188.4	1605.0	1655.2	1528.1	1530.2
Stanford	Domestic	Greece	106.4	104.7	152.5	172.6	125.5	129.0	119.1	119.4
Stanford	Domestic	Hungary	69.3	308.9	586.1	811.0	771.8	826.7	823.7	839.9
Stanford	Domestic	Ireland	18.1	36.3	58.4	72.8	62.1	65.4	63.4	64.2
Stanford	Domestic	Italy	414.3	773.3	1054.1	1154.6	839.0	856.1	787.1	785.9
Stanford	Domestic	Latvia	16.2	50.7	93.5	128.9	123.9	132.6	132.4	135.0
Stanford	Domestic	Lithuania	48.9	85.8	169.6	239.5	230.8	247.8	247.7	252.9
Stanford	Domestic	Luxembourg	2.0	3.7	5.2	5.9	4.6	4.8	4.5	4.6

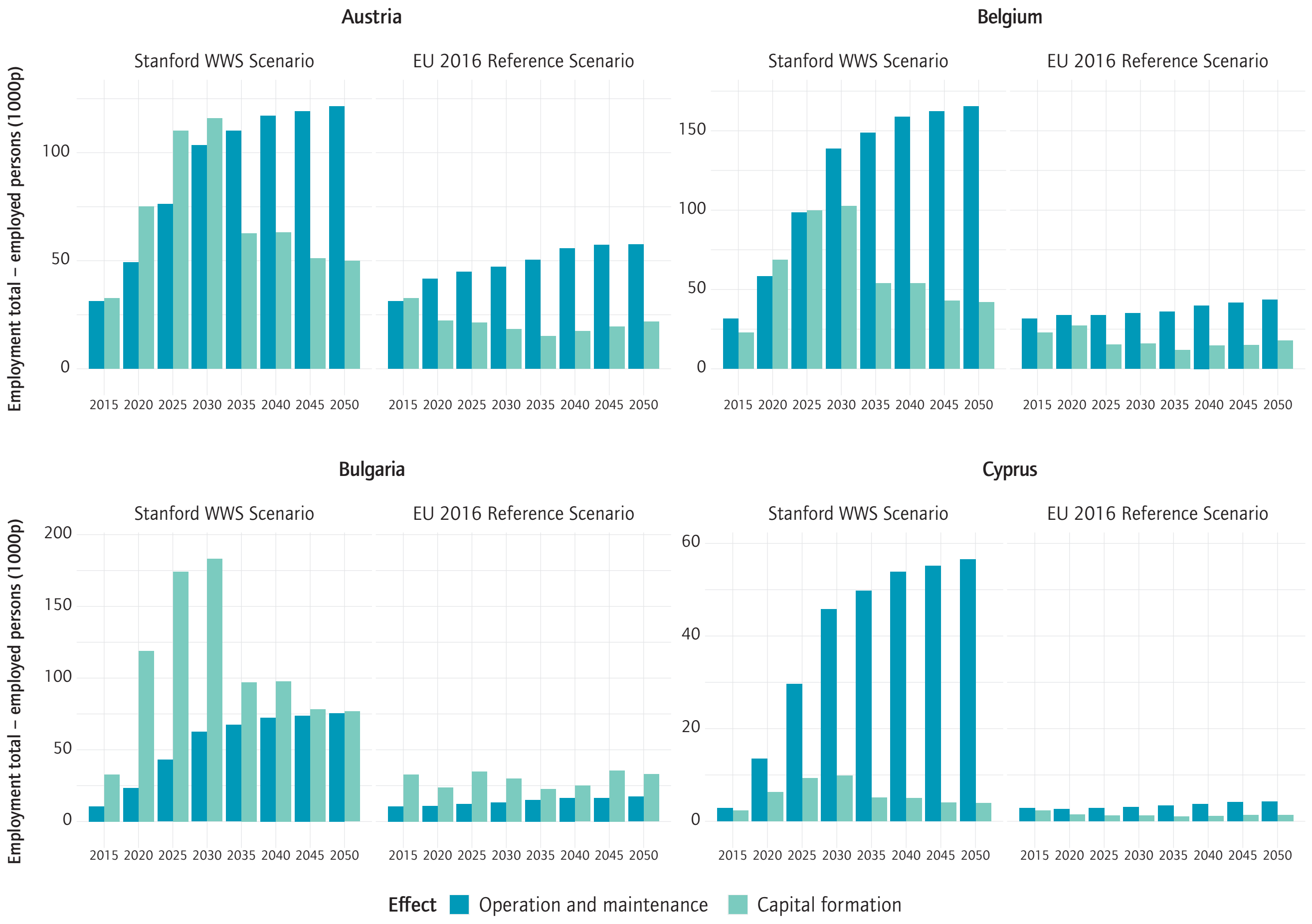
Employment effects by country			Employment total - employed persons (000)							
Scenario	**Origin**	**Country**	**2015**	**2020**	**2025**	**2030**	**2035**	**2040**	**2045**	**2050**
Stanford	Domestic	Malta	7.9	13.5	17.6	18.7	13.7	13.9	12.8	12.8
Stanford	Domestic	Netherlands	87.0	182.2	266.6	304.1	229.4	237.6	221.7	222.6
Stanford	Domestic	Poland	199.3	419.4	595.2	645.6	420.6	428.7	378.6	376.5
Stanford	Domestic	Portugal	72.8	118.3	163.5	182.4	137.8	141.0	131.7	131.9
Stanford	Domestic	Romania	204.7	276.1	348.4	350.9	219.4	217.6	**187.6**	**184.2**
Stanford	Domestic	Slovakia	53.1	98.2	143.1	169.1	139.9	145.7	139.7	140.9
Stanford	Domestic	Slovenia	35.1	45.5	67.9	78.3	58.5	60.7	56.5	56.7
Stanford	Domestic	Spain	254.3	446.2	610.4	687.5	542.5	557.2	526.7	528.5
Stanford	Domestic	Sweden	71.4	125.4	189.8	223.6	175.1	182.5	172.3	173.4
Stanford	Domestic	United Kingdom	339.1	598.1	871.3	989.8	740.2	760.9	709.5	711.7
EU Reference	Domestic	Austria	63.9	**63.8**	66.0	65.6	65.5	73.1	76.6	79.4
EU Reference	Domestic	Belgium	54.4	60.9	**49.2**	**50.7**	**47.8**	**54.4**	56.4	61.3
EU Reference	Domestic	Bulgaria	43.2	**34.8**	46.9	43.4	**37.9**	**41.5**	52.1	50.3
EU Reference	Domestic	Croatia	58.6	**30.3**	**39.0**	**35.0**	**38.8**	**41.9**	**44.7**	**45.9**
EU Reference	Domestic	Cyprus	5.1	**4.1**	**4.0**	**4.4**	**4.3**	**4.7**	5.4	5.6
EU Reference	Domestic	Czechia	97.9	**85.1**	**76.0**	**76.5**	**83.1**	**83.3**	**78.9**	**85.0**
EU Reference	Domestic	Denmark	38.2	**34.3**	**25.3**	**28.6**	**24.4**	**30.7**	**29.3**	**33.0**
EU Reference	Domestic	Estonia	26.1	**9.3**	**8.8**	**8.3**	**9.1**	**8.3**	**10.4**	**11.1**
EU Reference	Domestic	Finland	64.0	**39.7**	**28.1**	**29.8**	**28.0**	**32.6**	**33.4**	**30.5**
EU Reference	Domestic	France	360.5	391.2	**326.6**	**317.7**	**304.1**	389.7	396.4	434.4
EU Reference	Domestic	Germany	817.4	**673.5**	**537.2**	**589.8**	**555.4**	**585.3**	**632.0**	**683.0**
EU Reference	Domestic	Greece	106.4	**44.4**	**53.2**	**48.9**	**47.4**	**45.2**	**53.7**	**53.5**
EU Reference	Domestic	Hungary	69.3	87.6	84.6	75.6	96.4	100.7	104.0	107.8
EU Reference	Domestic	Ireland	18.1	**15.7**	**13.6**	**13.9**	**14.0**	**15.2**	**16.2**	**17.0**
EU Reference	Domestic	Italy	414.3	**407.1**	**403.4**	**400.4**	**405.0**	477.2	557.4	545.5
EU Reference	Domestic	Latvia	16.2	**14.4**	18.0	16.4	17.8	17.6	18.8	18.7
EU Reference	Domestic	Lithuania	48.9	**11.9**	**14.3**	**37.3**	**15.4**	**15.7**	**16.9**	**19.0**
EU Reference	Domestic	Luxembourg	2.0	2.0	**2.0**	2.2	2.5	3.0	3.5	3.4
EU Reference	Domestic	Malta	7.9	9.1	9.4	9.9	9.9	10.3	11.5	12.7
EU Reference	Domestic	Netherlands	87.0	103.4	**84.7**	**86.1**	88.7	95.7	100.2	106.8
EU Reference	Domestic	Poland	199.3	**166.5**	217.9	221.2	253.4	246.4	242.9	254.2
EU Reference	Domestic	Portugal	72.8	**71.7**	**60.5**	**65.3**	**53.1**	**55.7**	**56.3**	**56.2**
EU Reference	Domestic	Romania	204.7	**157.4**	**148.4**	**130.9**	**134.5**	**146.3**	**156.4**	**166.9**
EU Reference	Domestic	Slovakia	53.1	62.6	60.4	62.5	**50.7**	**52.9**	72.6	69.7
EU Reference	Domestic	Slovenia	35.1	**22.3**	**29.2**	59.6	87.9	124.0	95.4	87.5
EU Reference	Domestic	Spain	254.3	**253.5**	267.2	288.6	288.1	315.3	318.1	333.7
EU Reference	Domestic	Sweden	71.4	**51.0**	**50.0**	**51.8**	**52.8**	**64.9**	**57.7**	**61.7**
EU Reference	Domestic	United Kingdom	339.1	343.4	**230.2**	**266.7**	**241.9**	**268.6**	**292.4**	**300.5**
			Change in employment compared to 2015 (%)							
Stanford	Domestic	Austria		95%	192%	243%	171%	182%	166%	168%
Stanford	Domestic	Belgium		133%	264%	343%	272%	291%	277%	281%
Stanford	Domestic	Bulgaria		230%	403%	469%	281%	294%	252%	252%
Stanford	Domestic	Croatia		13%	67%	92%	45%	50%	40%	41%
Stanford	Domestic	Cyprus		287%	662%	986%	973%	1051%	1058%	1082%
Stanford	Domestic	Czechia		110%	204%	242%	145%	152%	131%	131%
Stanford	Domestic	Denmark		41%	103%	128%	67%	72%	59%	59%
Stanford	Domestic	Estonia		16%	106%	177%	160%	178%	176%	181%
Stanford	Domestic	Finland		37%	114%	153%	93%	101%	88%	90%

Employment effects by country			Change in employment compared to 2015 (%)							
Scenario	Origin	Country	2015	2020	2025	2030	2035	2040	2045	2050
Stanford	Domestic	France		90%	172%	208%	133%	140%	124%	125%
Stanford	Domestic	Germany		63%	137%	168%	96%	102%	87%	87%
Stanford	Domestic	Greece		-2%	43%	62%	18%	21%	12%	12%
Stanford	Domestic	Hungary		346%	746%	1070%	1014%	1093%	1089%	1112%
Stanford	Domestic	Ireland		100%	223%	302%	243%	262%	250%	255%
Stanford	Domestic	Italy		87%	154%	179%	102%	107%	90%	90%
Stanford	Domestic	Latvia		214%	478%	697%	667%	720%	719%	735%
Stanford	Domestic	Lithuania		75%	247%	389%	371%	406%	406%	417%
Stanford	Domestic	Luxembourg		86%	164%	200%	136%	144%	130%	131%
Stanford	Domestic	Malta		70%	122%	136%	72%	75%	61%	61%
Stanford	Domestic	Netherlands		109%	206%	250%	164%	173%	155%	156%
Stanford	Domestic	Poland		110%	199%	224%	111%	115%	90%	89%
Stanford	Domestic	Portugal		63%	125%	151%	89%	94%	81%	81%
Stanford	Domestic	Romania		35%	70%	71%	7%	6%	-8%	-10%
Stanford	Domestic	Slovakia		85%	170%	219%	164%	175%	163%	165%
Stanford	Domestic	Slovenia		29%	93%	123%	66%	73%	61%	61%
Stanford	Domestic	Spain		75%	140%	170%	113%	119%	107%	108%
Stanford	Domestic	Sweden		75%	166%	213%	145%	155%	141%	143%
Stanford	Domestic	United Kingdom		76%	157%	192%	118%	124%	109%	110%
EU Reference	Domestic	Austria		0%	3%	3%	2%	14%	20%	24%
EU Reference	Domestic	Belgium		12%	-10%	-7%	-12%	0%	4%	13%
EU Reference	Domestic	Bulgaria		-20%	9%	1%	-12%	-4%	21%	17%
EU Reference	Domestic	Croatia		-48%	-33%	-40%	-34%	-28%	-24%	-22%
EU Reference	Domestic	Cyprus		-19%	-21%	-14%	-15%	-8%	6%	10%
EU Reference	Domestic	Czechia		-13%	-22%	-22%	-15%	-15%	-19%	-13%
EU Reference	Domestic	Denmark		-10%	-34%	-25%	-36%	-20%	-23%	-14%
EU Reference	Domestic	Estonia		-65%	-66%	-68%	-65%	-68%	-60%	-58%
EU Reference	Domestic	Finland		-38%	-56%	-53%	-56%	-49%	-48%	-52%
EU Reference	Domestic	France		9%	-9%	-12%	-16%	8%	10%	20%
EU Reference	Domestic	Germany		-18%	-34%	-28%	-32%	-28%	-23%	-16%
EU Reference	Domestic	Greece		-58%	-50%	-54%	-55%	-57%	-50%	-50%
EU Reference	Domestic	Hungary		26%	22%	9%	39%	45%	50%	56%
EU Reference	Domestic	Ireland		-13%	-25%	-23%	-23%	-16%	-10%	-6%
EU Reference	Domestic	Italy		-2%	-3%	-3%	-2%	15%	35%	32%
EU Reference	Domestic	Latvia		-11%	11%	2%	10%	9%	16%	16%
EU Reference	Domestic	Lithuania		-76%	-71%	-24%	-69%	-68%	-66%	-61%
EU Reference	Domestic	Luxembourg		0%	0%	10%	28%	54%	78%	71%
EU Reference	Domestic	Malta		14%	18%	24%	25%	30%	45%	60%
EU Reference	Domestic	Netherlands		19%	-3%	-1%	2%	10%	15%	23%
EU Reference	Domestic	Poland		-16%	9%	11%	27%	24%	22%	28%
EU Reference	Domestic	Portugal		-2%	-17%	-10%	-27%	-24%	-23%	-23%
EU Reference	Domestic	Romania		-23%	-27%	-36%	-34%	-29%	-24%	-18%
EU Reference	Domestic	Slovakia		18%	14%	18%	-4%	0%	37%	31%
EU Reference	Domestic	Slovenia		-37%	-17%	70%	150%	253%	172%	149%
EU Reference	Domestic	Spain		0%	5%	13%	13%	24%	25%	31%
EU Reference	Domestic	Sweden		-29%	-30%	-28%	-26%	-9%	-19%	-14%
EU Reference	Domestic	United Kingdom		1%	-32%	-21%	-29%	-21%	-14%	-11%

Source: EXIOBASE 3.6, Stanford WWS Scenario, EU 2016 Reference Scenario and the sources for employment accounts and installed capacity listed in Section 3, own calculation (Capros et al. 2016; Jacobson et al. 2019; Stadler et al. 2018)

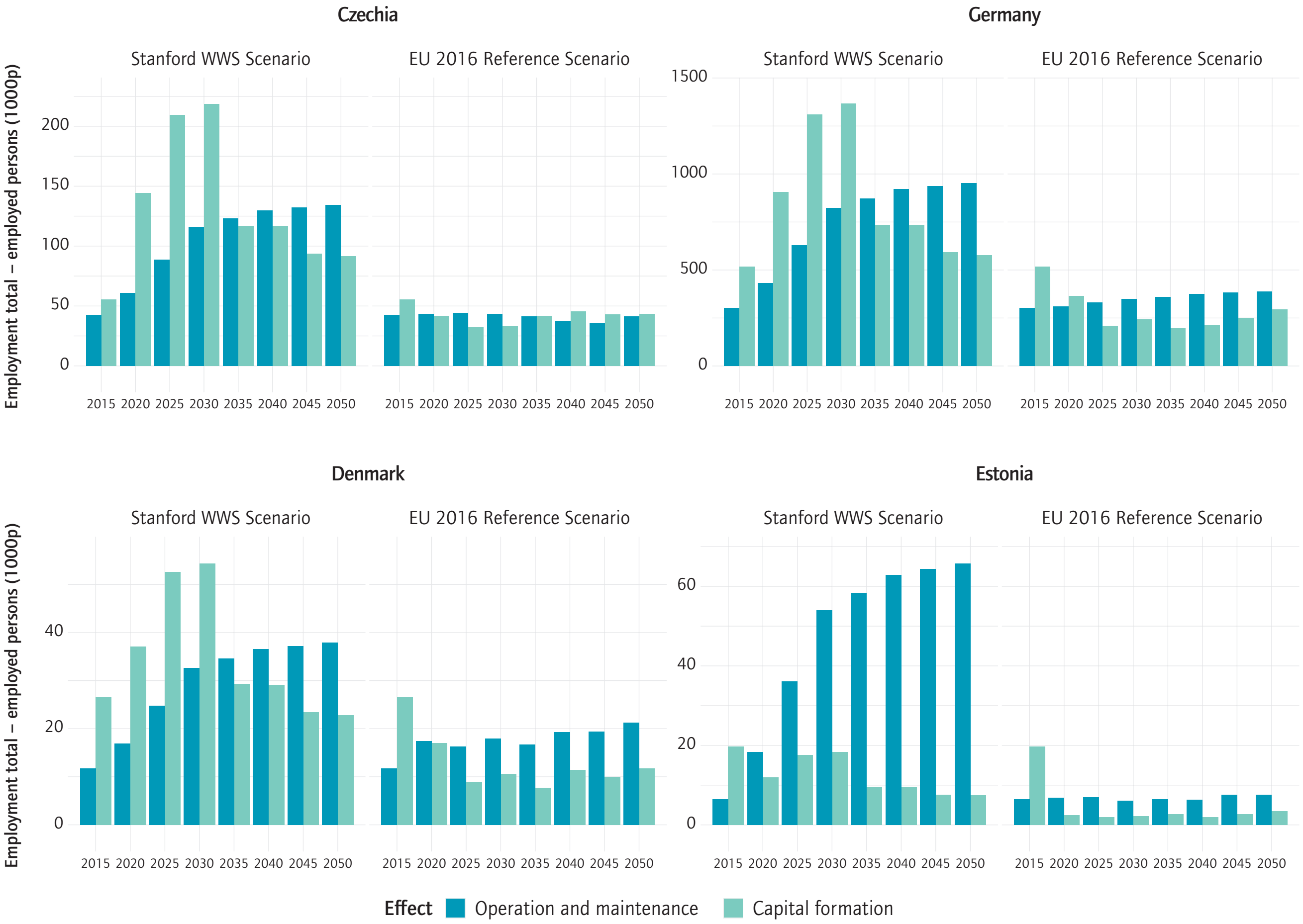
8.4.2 Results by countries (operation and maintenance vs. capital formation employment effects)

Figure 14 **Direct and indirect employment effects related to changes in the energy mix in electricity production in the EU27+UK by capital formation vs. operation and maintenance (domestic for Austria, Belgium, Bulgaria and Cyprus)**



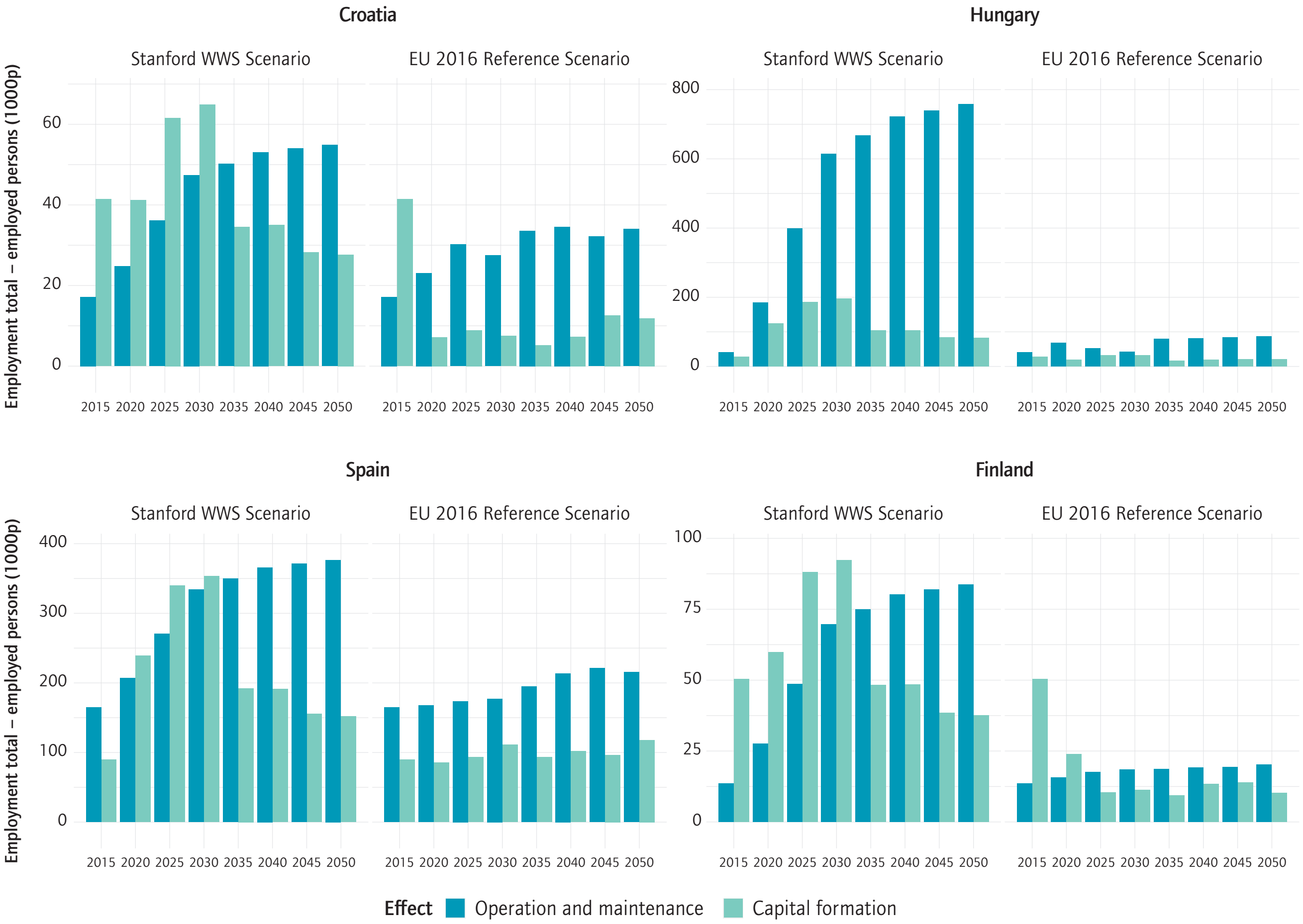
Source: EXIOBASE 3.6, Stanford WWS Scenario, EU 2016 Reference Scenario and the sources for employment accounts and installed capacity listed in Section 3, own calculation (Capros et al. 2016; Jacobson et al. 2019; Stadler et al. 2018)

Figure 15 **Direct and indirect employment effects related to changes in the energy mix in electricity production in the EU27+UK by capital formation vs. operation and maintenance (domestic for Czechia, Germany, Denmark and Estonia)**



Source: EXIOBASE 3.6, Stanford WWS Scenario, EU 2016 Reference Scenario and the sources for employment accounts and installed capacity listed in Section 3, own calculation (Capros et al. 2016; Jacobson et al. 2019; Stadler et al. 2018)

Figure 16 **Direct and indirect employment effects related to changes in the energy mix in electricity production in the EU27+UK by capital formation vs. operation and maintenance (domestic for Croatia, Hungary, Spain and Finland)**

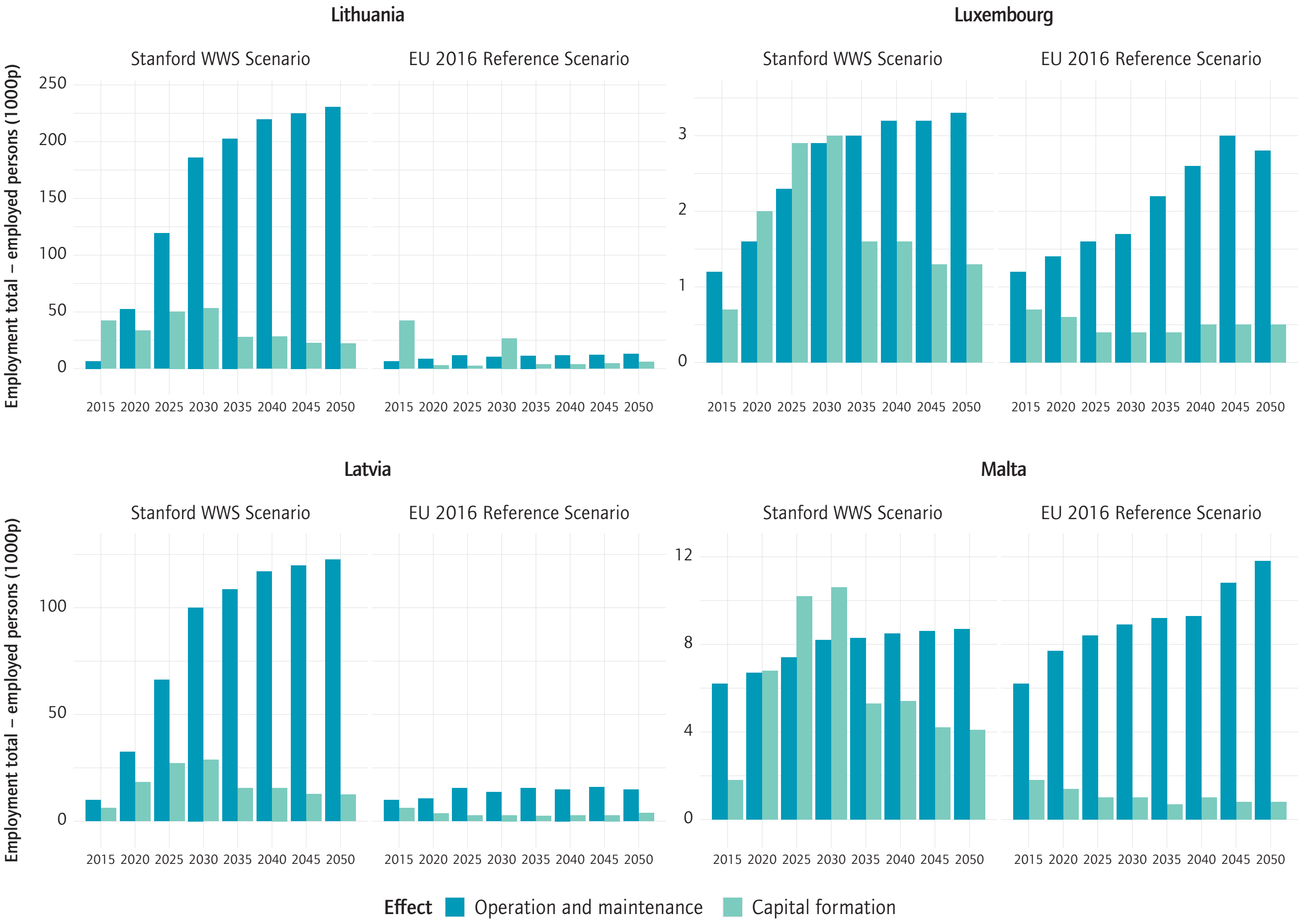


Source: EXIOBASE 3.6, Stanford WWS Scenario, EU 2016 Reference Scenario and the sources for employment accounts and installed capacity listed in Section 3, own calculation (Capros et al. 2016; Jacobson et al. 2019; Stadler et al. 2018)

Figure 17 **Direct and indirect employment effects related to changes in the energy mix in electricity production in the EU27+UK by capital formation vs. operation and maintenance (domestic for France, Greece, Ireland and Italy)**

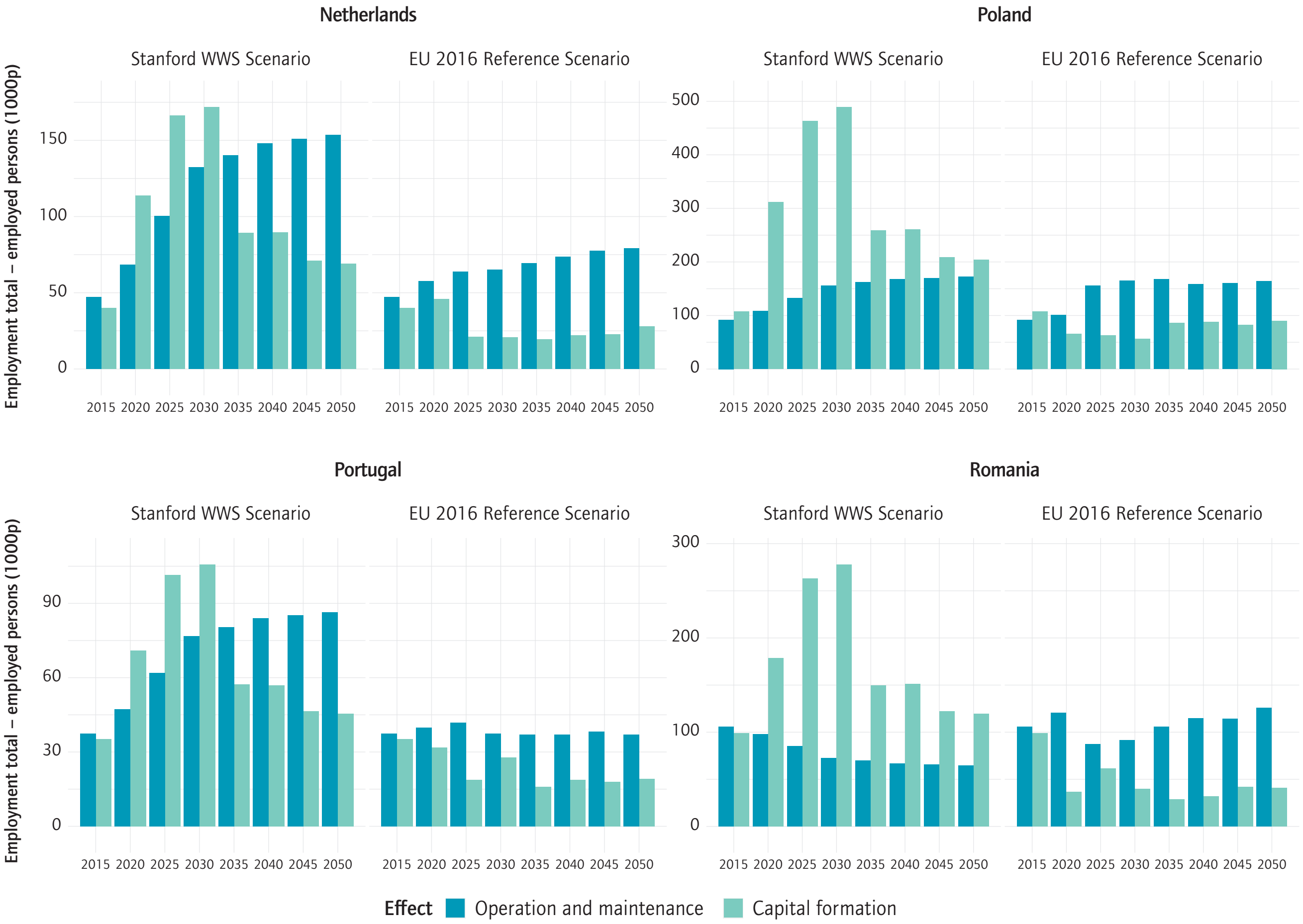
Source: EXIOBASE 3.6, Stanford WWS Scenario, EU 2016 Reference Scenario and the sources for employment accounts and installed capacity listed in Section 3, own calculation (Capros et al. 2016; Jacobson et al. 2019; Stadler et al. 2018)

Figure 18 **Direct and indirect employment effects related to changes in the energy mix in electricity production in the EU27+UK by capital formation vs. operation and maintenance (domestic for Lithuania, Luxembourg, Latvia and Malta)**



Source: EXIOBASE 3.6, Stanford WWS Scenario, EU 2016 Reference Scenario and the sources for employment accounts and installed capacity listed in Section 3, own calculation (Capros et al. 2016; Jacobson et al. 2019; Stadler et al. 2018)

Figure 19 **Direct and indirect employment effects related to changes in the energy mix in electricity production in the EU27+UK by capital formation vs. operation and maintenance (domestic for the Netherlands, Poland, Portugal and Romania)**



Source: EXIOBASE 3.6, Stanford WWS Scenario, EU 2016 Reference Scenario and the sources for employment accounts and installed capacity listed in Section 3, own calculation (Capros et al. 2016; Jacobson et al. 2019; Stadler et al. 2018)

Figure 20 **Direct and indirect employment effects related to changes in the energy mix in electricity production in the EU27+UK by capital formation vs. operation and maintenance (domestic for Sweden, Slovenia, Slovakia and the United Kingdom)**

Source: EXIOBASE 3.6, Stanford WWS Scenario, EU 2016 Reference Scenario and the sources for employment accounts and installed capacity listed in Section 3, own calculation (Capros et al. 2016; Jacobson et al. 2019; Stadler et al. 2018)

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