Employment effects of renewable energy deployment – a review

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Abstract: The paper investigates a central hypothesis of the green economy concept which states that transitioning to a low-carbon economy is justified on an economic basis. We analyse this hypothesis by focussing on employment effects from renewable energy deployment, based on an evaluation of impact studies from peer-reviewed journals. The studies are categorised according to employment factors or model-based scenario assessments on employment effects from renewable policies. The applied methodologies and the type of employment effects – direct, indirect, induced, gross, net – are distinguished. Given the heterogeneity of assumptions, the results are hardly comparable, although we find that a majority of the investigated scenarios show positive net employment effects. The positive link between renewable energy deployment and job creation is, however, not straightforward, as different assumptions, system boundaries and modelled interactions such as the crowding out of alternative energy production or effects from prices, income and foreign trade influence the results.

Keywords: renewable energy; employment effects; climate mitigation; green economy.

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1 Introduction

The interest in analysing employment effects and exploring the environment-economy intersection of a transition towards a low-carbon and resource-efficient economy arises within the context of undesirable developments in both of these areas. There is growing evidence that humanity faces severe environmental degradation based on the unsustainable production and consumption patterns of modern industrialised societies (UNEP, 2012). Energy- and resource-intensive lifestyle patterns of industrialised countries are aspired in emerging and developing countries that show high economic growth rates and exhibit fast-growing populations. Correlated economic activities, ranging from transportation, manufacturing and services to agriculture and mining, to a very large extent still globally rely on fossil fuel combustion. This generates pollution and greenhouse gas emissions, which, in sum, undermine critical ecosystem services and life-support systems, thus affecting human well-being in a detrimental way. Climate change appears as just one key challenge humanity faces, in addition to and interlinked with air and water pollution, desertification, biodiversity loss, overfishing, acidification of oceans and deforestation (Rockström et al., 2009).

With respect to the labour market, Europe and the world are facing stagnating economies with high and rising unemployment rates, particularly among young people. Youth unemployment rates in Europe reached 23.5% in the first quarter of 2013 – more than twice the rate for the overall population. In some countries, more than half of young people under the age of 25 are unemployed (European Commission, 2013). Around the world, almost 202 million people were unemployed in 2013, which amounted to about 5 million more compared to 2012. At the same time, about 74.5 million young people aged 15 to 24 years were unemployed (2013), which was about 1 million more than in 2012 (ILO, 2014). The global youth unemployment rate has reached 13.1%, which is almost three times as high as the global adult unemployment rate. Indeed, the youth-to-adult unemployment ratio has reached a historical peak, with particular high rates occurring in the Middle East, North Africa, Latin America and Southern Europe (ILO, 2014).

These socio-ecological changes suggest a mismatch with the objectives of a sustainable development that would be characterised by environmentally benign and socially inclusive production and consumption patterns securing the long term progress of societies. Tackling these problematic trends, the concept of a ‘green economy’ was laid down by the United Nations Environment Programme (UNEP) in late 2008 and has become a topic of international institutions and research agendas. It is defined as low in carbon, resource-efficient and socially inclusive. It “…results in improved human wellbeing and social equity, while significantly reducing environmental risks and ecological scarcities” (UNEP, 2011). The central hypothesis of the green economy concept maintains that transitioning to a green economy has sound economic justification. In fact, positive economic impacts from transitioning towards a low-carbon economy are important additional arguments for public engagement in long-term climate mitigation policies, in particular in times of tight fiscal budgets. Overall, the analysis of the co-benefits of environmental policies is gaining increasing importance in the scientific analysis of policies directed towards sustainable development goals [IPCC, (2014), Chapter 6].

The paper evaluates the hypothesis of sound economic impacts from transitioning to a low-carbon economy by focussing on employment effects from renewable energy deployment. A review of scientific papers that quantify these effects is conducted. The main purpose of the paper is to explore whether there is scientific evidence from the literature that transitioning to a low-carbon economy creates net employment effects. The paper focuses on the employment potential of renewable energy technologies and thus on mitigating climate change. All remaining environmental challenges of transitioning to a green economy such as material consumption and waste deposition, overfishing, etc., are not considered in the present analysis.

Renewable energy sources (RES) and technologies play a crucial role in mitigating climate change and providing energy for services such as lighting, cooking, space heating, mobility, communication and production processes (IPCC, 2011).[1] Multiple technologies and types of renewable energy from solar, geophysical (wind, water) or biological (biomass) sources are becoming increasingly cost-effective. They can supply electricity, thermal energy and mechanical energy as well as liquid fuels, while lowering GHG emissions from the energy systems. RES release little or no additional direct CO_2 emissions.[2] The combustion of fossil fuels, in contrast, was responsible for 56.6% of all anthropogenic GHG emissions (CO_{2eq}) in 2004 (Rogner et al., 2007). On a global basis, RES accounts for 13% of total primary energy supply and this share varies substantially by country and region (2010, IEA data base). While the contribution of RES to the primary energy supply is still rather small, the deployment of RES has increased rapidly in recent years. In 2013, the worldwide renewable power capacity grew by 8.3% with respect to 2012, exceeding 1,500 GW in 2012 (REN21, 2014). Hydropower rose by 4.2% to an estimated 1,000 GW, while wind power grew by 12% to 318 GW and solar PV by 39% to 139 GW. The global theoretical potential of RES greatly exceeds both current energy use and the projected future global energy demand. The technical potential for solar energy is highest among RES (Moomaw et al., 2011). There appears thus to be no limit to the continued market growth of RES technologies. However, due to the public good character of climate protection and due to the fact that RES technologies are competing with low cost fossil fuels such as coal and natural gas, and in particular unconventional oil and gas, the transition to a low-carbon energy system requires strong government initiative, and stable political frameworks for investment and private engagement. Assessments of the employment effects of a renewable energy transition may support public and private commitments to sustainable energy systems.

The remainder of the paper is structured as follows: Section 2 deals with the concept of ‘green employment’, presenting its central definitions and limitations. Section 3 delineates methodologies to quantify employment effects. Section 4 presents data on renewable job creation (4.1), and an assessment of peer-reviewed studies on employment effects from renewable deployment (4.2). Conclusions and policy implications are drawn in Section 5.

2 Green employment: a concept in transition

Given the necessity to de-carbonise the current energy system and make a transition to environmentally benign production and consumption patterns, and given the challenges of overcoming economic stagnation and increasing employment shares, the concept of the ‘green economy’ has been launched by the UNEP in 2008 (UNEP, 2011; UNEP et al., 2008). In an ideal state, "…a green economy is one that does not generate GHG emissions, pollution or waste and is hyper-efficient in its use of energy, water, and materials" [UNEP et al., (2008), p.35].[3] Green employment represents a keystone of transitioning to a green economy as defined by UNEP because green jobs contribute to maintaining or restoring environmental quality and avoiding future damage to the earths' ecosystems (UNEP et al., 2008). In particular, green jobs are "...positions in agriculture, manufacturing, construction, installation, and maintenance, as well as scientific and technical, administrative and service-related activities that contribute substantially to preserving or restoring environmental quality. Specifically, but not exclusively, this includes jobs that help to protect and restore ecosystems and biodiversity, reduce energy, materials and water consumption through high-efficiency and avoidance strategies, de-carbonize the economy and minimize or altogether avoid generation of all forms of waste and pollution" (UNEP et al., 2008).

This qualitative description delivered by UNEP allows for a broad range of green employment but it does not give a clear and precise definition. A coherent systematic approach for different categories of green jobs that could be commonly applied and statistically measured is yet missing. Green jobs are also not well-captured in government or other statistics, because green employment cuts across different sectors of the economy. Data on green jobs are hence spread across different sectors of industrial classification systems, e.g. of the European statistical classification of economic activities (NACE[4]) or the North American Industry Classification System, and must be especially assembled. Examples of such cross-sectoral industries are the environmental goods and services industry (Eurostat, 2009; OECD, 1999) or the tourism industry (Eurostat, 2001).

Generally, data on green employment are available for certain segments, such as specific industries or countries, and they tend to be a snapshot rather than representing consistent time-series and to be estimates and projections more than firm figures (Eurostat, 2009; IRENA, 2013). One of the challenges of the concept is to characterise and typify green jobs in order to develop a meaningful statistical concept. Gathering information on green jobs is essential for enabling informed policy choices and monitoring policy effectiveness. It also helps communicate the benefits of greening the economy to a wider public. Some examples may illustrate the endeavour to find coherent measures on green employment that are generally applicable (UNEP et al., 2008):

- Efficiency improvements are a core requirement for a transition to a low-carbon economy. However, employment in new technologies, business practices or shifts in professions that yield improved energy efficiency are difficult to separate from regular employment, as they occur in existing industries and achieve the same economic output and level of well-being (c.p.) but with less energy. In addition, efficiency is a relative and dynamic concept. Today's efficiency can become marginal tomorrow as technology and efficiency standards advance.

- The production of environmentally-friendly technologies often labelled 'environmental industries' or 'green tech' is considered to contribute to a low-carbon and green economy. These technologies span a broad spectrum of products and services that use new, innovative technologies to create products and services with less of a detrimental impact on the environment. Pollution control and end-of-pipe technologies constitute a substantial part of this concept (Eurostat, 2009). However, it is not clear whether employment related to pollution control technologies shall be considered 'green' because these technologies remain part of a resource- and waste-intensive economy. The transition toward a low-carbon, green economy requires a more fundamental shift away from energy and material consumption. The importance of downstream environmental clean-up and protection technologies is in fact decreasing in developed countries, while at the same time the importance of resource-saving technologies like renewable energy, energy efficiency and recycling is growing (Jänicke, 2012).

- Newly emerging sectors of the economy such as renewable energy production lack long-track empirical data. Relevant employment data is either derived from industry surveys or from macro-economic/econometric modelling, based on input-output (I-O) tables that capture direct and indirect employment, in order to estimate net employment effects (Section 4).

The green jobs or green employment concept thus remains fuzzy and appears to lack a fixed definition. As technology progresses and newly emerging technologies and economic sectors evolve, different standards of what is 'green' and what is defined as 'low-carbon' will apply. A realistic or pragmatic approach towards green jobs is therefore process-oriented and remains open for new technologies in different sectors of the economy. Nonetheless, a conceptual perspective on green employment can be derived as a guiding principle to quantify green jobs. Based on this, the transition towards a low-carbon, green economy would involve the following employment shifts:

- additional jobs being created
- some employment being substituted
- some jobs being eliminated without replacement
- many existing jobs being redefined as greened skills, methods and profiles.

To be precise about the quantity of green jobs being reported, it should be indicated whether these relate to gross or net employment effects (Section 3). Other classifications of green jobs refer to direct, indirect and induced employment effects. Investments in environmentally-friendly economic activities generate a certain number of direct and indirect jobs from intermediate supply, while induced jobs are created through additional consumer spending from direct and indirect job earnings. However, it remains an open question whether induced jobs in sectors of the economy that are not related to, for instance, renewable energy shall be considered 'green'. If the additional income is spent on energy- and material-intensive goods and services (e.g. long-distance travel), the induced employment cannot be considered green as it compensates, at least in part, for the environmental gains derived from renewable energy supply.[5] However, such qualitative distinctions have not yet been made in modelling employment effects from renewable energy deployment and thus cannot be separated out in net employment analyses. Our review (Section 4) and generally our paper therefore accounts for all net employment effects of renewable energy deployment and is not limited to green employment.

Another useful distinction of job categories is the stage of job creation within the lifecycle of the resource or energy saving technology. That is, whether jobs are created in R&D, in production, construction and installation or in operation and management (O&M) is relevant for domestic job creation because production may take place abroad, while O&M stays within a country.

Finally, a central guiding question in defining green jobs is whether investment in environmentally benign technologies is more or less labour intensive and results in more or less pollution per unit of spending than investment in alternatives. The reduction in GHG emissions from investment in low-carbon technologies should be substantial and not merely marginal in order to be deemed ‘green’. Therefore, one strategic approach towards establishing a ‘green economy’ must be to place a stronger emphasis on improving resource productivity rather than labour productivity.

The following section presents an overview of state-of-the-art methods of measuring employment from renewable energy deployment. Renewable energy deployment is selected as a key example for green jobs, because it is a highly dynamic and evolving low carbon sector of the economy. The section presents the latest available data on renewable energy employment and gives an overview of basic methodologies for measuring employment effects.

3 Methodologies for assessing employment effects

Model assessments of employment creation from renewable energy deployment are necessarily based on various assumptions. These include assumptions about energy price developments, technological developments and country- or region-specific policy goals (increasing the share of renewables by xy%). Employment projections may be based on different policy measures that provide incentives for renewable energy deployment, such as carbon pricing by taxes or certificates or feed-in tariffs, and apply different financing and investment schemes. In addition, model projections are derived from different methodologies and based on different datasets. This results in a lack of comparability of the studies projecting employment effects from renewables.

The following sections present an overview of the different methodologies available for assessing renewable employment creation. Employment estimates in the renewable energy literature are typically based on three types of methodologies: the employment factor approach, supply chain analysis or I-O modelling, as well as methods drawing on I-O tables, such as general equilibrium models. As mentioned above, in order to be precise about the employment results, it is important to distinguish between gross and net employment effects and whether only direct employment effects are accounted for or whether indirect or induced employment effects are also taken into account.

Gross employment studies only focus on the economic relevance of the particular renewable energy sector. Gross employment assessments neglect any potential negative job effects that may occur in alternative sectors, for example, by substituting jobs in fossil fuel and nuclear energy or via reduced consumption activities due to increased energy prices. These studies therefore emphasise the positive side of investing in and financing renewables. Depending on the scope of investigation, employment effects may be smaller or greater if indirect and induced employment effects are taken into consideration. To include the effects on upstream industries and thereby consider employment from intermediate inputs, the assessment requires a multiplier analysis based on an I-O table approach or a supply chain analysis. Some studies suggest that the number of indirect jobs is generally larger than the number of direct jobs for all renewable energy technologies (Lehr et al., 2011).

Net employment studies are conducted by comprehensive economic models [e.g. computable equilibrium models (CGE) or macro-econometric models] and relate to all employment impacts including those which occur beyond the renewable energy industry. Net employment studies portray the change in the number of jobs in the total economy. In particular, economy-wide price, income and substitution effects are taken into account. These may affect the consumption of households or the production of intermediate products and services, as well as the competitiveness of entire industries, which arises due to altered energy prices. Net employment effects are thus derived by summarising positive and negative direct, indirect and induced effects of renewable energy deployment (Breitschopf et al., 2011). Net employment may be negative depending on which repercussions are taken into account. In our review (Section 4) we find a significant difference in net employment results, depending on whether higher energy prices, feed-in tariffs or a consistent public spending scheme is considered in modelling employment effects. However, these policy system boundaries vary significantly between studies and are subject to determination by authors of models.

In general, care must be taken in distinguishing between net and gross effects. As gross employment studies show much higher renewable employment effects, these tend to be cited more favourably in the policy arena, because the justification of public expenditure on renewables is more fundamental.

Table 1 provides an overview of the interrelations between result categories (gross, net, direct, indirect and induced) and methodologies found in the literature. Several methods can be implemented to investigate specific result categories. The supply chain approach and employment factor approach, for instance, are mainly applicable for the case of direct job effects, but may be used to assess first-round indirect job effects as well. They cover neither full inter-sectoral nor income effects. CGE models are not suited for gross effects. Even though it is possible to simulate gross effects, this type of model has built-in interrelations, which fully take into account crowding-out effects, for example, from the promotion of renewable energy technologies. The most prevalent approach is the I-O model. This model is very adaptable and commonly used in examining every result category.

Table 1 Employment effects and methodologies

Employment	*Direct*	*Indirect*	*Induced effects*
Gross effects	Supply chain analysis	Employment factor**	I-O *
	Employment factor	I-O	
	I-O		
Net effects	I-O *	I-O *	I-O *
	CGE	CGE	CGE

Notes: *Using specified adaptations and/or extensions (further assumptions, additional sub models and others)
**Only in case where a literature-based ‘indirect employment coefficient’ is applied.

Source: Own representation

3.1 Employment factor approach

The easiest and quickest method of assessing direct jobs from renewables is the employment factor approach. Employment factors indicate the number of jobs (measured as full-time equivalents) created per physical unit, e.g. installed peak capacity or produced energy expressed as megawatts (MW) or megawatt-hours (MWh) for electricity generation, heat production or fuel supply (IRENA, 2013). To estimate the total number of direct jobs, employment factors are multiplied by a certain renewable energy capacity. The employment factor approach applies different employment factors for different phases of the life cycle, such as R&D, manufacturing, construction, installation and O&M. For bioenergy, the fuel supply phase is considered an additional activity (growing, harvesting and transportation of feedstock). Different employment factors of the same phase of the life cycle for a particular renewable energy technology may relate to regional particularities – that is, whether manufacturing takes place in highly industrialised countries or in less developed countries influences the labour intensity of the life cycle stage. As the manufacturing of renewable energy technologies may occur abroad, the application of employment factors must take into account the structure of international trade in manufacturing. This means that countries exporting renewable technologies and components generate employment in addition to their domestic renewable energy capacity, and the installed renewable capacity may not be misinterpreted as an indicator for renewable employment (IRENA, 2013). Denmark is often cited as an example of this, as it has a large wind turbine manufacturing sector (high employment rate) with most of the components exported. This situation significantly inflates the ratio of jobs-per-MW-installed (Lambert and Silva, 2012).

In general, the number of jobs per unit of capacity is considerably lower for O&M than for manufacturing, construction and installation (MCI), but O&M generates employment over the lifetime of the respective technologies, while MCI may require several months to a few years only. O&M employment factors are applied to the total installed capacity, whereas MCI employment factors only refer to newly added capacities (IRENA, 2013). Furthermore, employment factors tend to decline with technology maturity and increasing labour productivity. Many renewable technologies are still in an early stage of development; therefore, cost degressions and economies of scale are expected to occur in the future, resulting in lower employment factors. Table 2 provides an overview of employment factors from OECD countries applied in the Energy [R]evolution scenario (Greenpeace International et al., 2012). Where local factors are not available, employment projections for non-OECD countries are based on regional adjustments of employment factors. In emerging and developing countries, labour productivities remain considerably lower, thus showing much higher per-MW job figures. For instance, studies estimated a range of 30 to 46.6 jobs per MW for MCI in wind energy in China and 37.5 jobs per MW for MCI in India (IRENA, 2013). As the renewable energy industry exhibits rapidly evolving labour productivities, estimates of employment factors need to be continuously revised.

Table 2 Employment factors used in global analysis

Fuel	*Manufacturing*	*Construction and installation*	*Operation and maintenance*	*Fuel – primary energy demand*
	Jobs/MW	*Job-years/MW*	*Jobs/MW*	*Jobs/PJ*
Biomass	2.9	14	1.5	32
Hydro – large	1.5	6	0.3	
Hydro – small	5.5	15	2.4	
Wind onshore	6.1	2.5	0.2	
Wind offshore	11	7.1	0.2	
PV	6.9	11	0.3	
Geothermal	3.9	6.8	0.4	
Solar thermal	4	8.9	0.5	
Geothermal – heat	3.0 jobs/MW (construction and manufacturing)			
Solar – heat	7.4 jobs/MW (construction and manufacturing)			

Source: Greenpeace International et al. (2012), own adaptations

3.2 Supply chain analysis

Supply chain and I-O analysis are used to calculate both direct and indirect employment effects, thus covering intermediary inputs and related services throughout all stages of the life cycle.

Supply chain analysis generates figures on direct and partly indirect jobs (first-round indirect effects) by mapping the specific supply hierarchy and relationships among companies of a specific renewable technology. This method is, however, rarely applied compared to the employment factor approach and the I-O analysis, because it is more of a project-specific analysis than a method for calculating sector-wide effects. In fact, it is a bottom-up microeconomic approach based on business surveys and statistical data analysis and thus less suited for macro-economic modelling and assessment. Within the supply chain analysis, stages of production and services ranging from the provision of raw materials to renewable energy production itself are determined by defining hierarchical tiers. Companies in the various tiers are then identified and data on capacity, project costs, labour and other inputs, turnover and production values are gathered for each tier in the supply chain. This involves questionnaires, interviews, financial and other surveys, in addition to the application of statistical data. Finally, labour inputs are related to the respective output capacity (IRENA, 2013; Llera et al., 2013).

3.3 I-O analysis

I-O analysis offers an analytical framework for assessing direct and indirect or direct, indirect and induced employment creation from renewable energy deployment. I-O tables are a well-established technique of economic data representation rooted in economic theory. They provide detailed information on the flows of intermediary goods and services among all sectors of the economy, as well as on the interdependencies of a country’s economy with the rest of the world (IRENA, 2013; Breitschopf et al., 2011). However, as renewable deployment represents a cross-cutting activity along the well-established different sectors of the economy, developing new technology-specific I-O tables for different renewables could be very helpful. For instance, Lehr et al. (2008) continue work started by Staiß et al. (2006) which integrates ten renewable energy technologies as production vectors to the German I-O tables. This work is based on a recurring survey of companies about their input structure and whether they sell to end consumers or produce intermediary goods for other industrial producers (IRENA, 2013).

The question of whether the deployment of renewable energy is beneficial from an economy-wide perspective must be assessed within a framework that captures all induced employment effects, such as, for example, changes in consumption when renewable energy employment translates into rising incomes and increased spending on goods and services. It also captures the effects of net employment losses due to the substitution of fossil fuel-based employment or rising electricity prices from renewable energy, which affect spending on the consumption of other goods and services. In order to assess the net effects, two future scenarios are compared with each other: a reference or business-as-usual scenario and a scenario with an ambitious renewable energy policy. Comparing these two yields additional employment and value added. These calculations are typically carried out using a complex economic model, such as a computable general equilibrium (CGE) model that draws on social accounting matrixes (extended version of I-O models) as data bases.

Major points of criticism of I-O-based approaches concern the high aggregation of I-O tables, which can prevent the adequate capturing of specific renewable technologies and their employment effects (e.g. PV or wind), as well as the fact that some I-O-based modelling assumes a constant structure of the economy based on fixed I-O tables. Some advanced models build on flexible I-O structures which however are not necessarily more adequate. This also strongly depends on the time perspective of modelling and the ability to forecast future technological and production structures. In light of large economic transformations and long time horizons such as in an energy transition, these approaches can significantly depart from reality, and therefore all quantitative results on employment figures must be interpreted carefully.

4 Renewable energy deployment and job creation

4.1 Empirical data on renewable employment

The renewable energy industry has grown rapidly in recent years. A descriptive data analysis of worldwide renewable job creation has been compiled by the International Renewable Energy Agency (IRENA, 2013). It addresses solar power, solar thermal energy (water heating), wind, small scale hydro power, geothermal energy (heat and power applications) and bioenergy (biomass for heat and power generation as well as transportation). The report assembles information from a wide variety of publicly available reports, studies and data bases originating from literature by government ministries, international agencies, industry associations, non-governmental organisations, consultancies and academic institutions. According to this, the majority of renewable energy employment is concentrated in China, Brazil, the European Union, the USA and India (Table 3). These countries are the biggest manufacturers of renewable energy equipment, producers of bioenergy feedstock and installers of production capacity. However, other countries are following suit by boosting their investments and policies in support of renewable energy deployment, and thereby creating jobs, mostly in operations and maintenance activities.

Table 3 Employment in renewable energy globally and for selected countries/regions

	European Union (EU)							
	Germany	*Spain*	*Other EU*	*USA*	*China*	*India*	*Brazil*	*World*
				1,000 jobs				
Biomass	57	39	178	152	266	58	.	753
Biofuels	23	4	82	217	24	35	804	1,379
Biogas	50	1	20	.	90	85	.	266
Geothermal	14	0	37	35	.	.	.	180
Small hydropower	7	2	18	8	.	12	.	109
Solar PV	88	12	212	90	300	112	.	1,360
CSP	2	18	.	17	.	.	.	37
Solar heating/cooling	11	1	20	12	800	41	.	892
Wind power	118	28	124	81	267	48	29	753
Total	370	105	691	612	1,747	391	833	5,729
				Percentage of world				
Biomass	7.6	5.2	23.6	20.2	35.3	7.7	.	100
Biofuels	1.7	0.3	5.9	15.7	1.7	2.5	58.3	100
Biogas	18.8	0.4	7.5	.	33.8	32.0	.	100
Geothermal	7.8	0.2	20.6	19.4	.	.	.	100
Small hydropower	6.4	1.8	16.5	7.3	.	11.0	.	100
Solar PV	6.5	0.9	15.6	6.6	22.1	8.2	.	100
CSP	5.4	48.6	.	45.9	.	.	.	100
Solar heating/cooling	1.2	0.1	2.2	1.3	89.7	4.6	.	100
Wind power	15.7	3.7	16.5	10.8	35.5	6.4	3.9	100
Total	6.5	1.8	12.1	10.7	30.5	6.8	14.5	100

Notes: Data are mostly from 2009–2012; the last column is derived from the world totals of employment. CSP: concentrated solar power.

Source: IRENA (2013), own calculation

Employment trends vary across renewable energy technologies. The increase in biofuel capacity leads to employment creation, in particular with respect to biomass feedstock production. The cultivation and harvesting of biomass feedstock is more labour-intensive than other technologies, however, the mechanisation of feedstock operations reduces related labour needs. Jobs in solar photovoltaic energy have surpassed those in wind in the last three to four years, with about 1.36 million direct and indirect jobs created worldwide. A key driver for the dynamic uptake of solar panels has been the substantially lower cost of solar panels, which triggered a boom in installations and consequently in O&M. Chinese companies have become the world's largest PV manufacturers, with 300,000 people employed in this sector (IEA, 2013). Solar heating and cooling account for about 800,000 jobs, and China is by far the world leader in solar hot water with more than 80% of global installations. Concentrated solar power (CSP) is still in its infancy compared to solar PV and solar water heating, with 37.000 jobs only. Spain and the USA currently lead the market for CSP, reaching 76% and 20% of global installed capacity, respectively, at the end of 2012 (REN21, 2013). The Middle East and North Africa (MENA) region is emerging as an attractive market for CSP deployment, driven inter alia by the motivation to create local employment opportunities. Employment driven by growing wind energy capacity has more than doubled between 2007 and 2012 (IRENA, 2013). Europe has long been the leader in wind energy, both in the manufacturing of wind turbines and parts and the development and operation of wind energy in the region. At the same time, the industry is expanding quickly to other parts of the world. For example, in 2012 China and the USA achieved the majority of added wind energy capacity, surpassing Germany and India. Other countries such as Japan, Australia, Brazil and Mexico are steadily increasing their wind energy capacity, creating employment in this field.

IRENA (2013) notes that for most countries data on renewable energy employment are only available for a single year or for scattered periods of time, limiting the conclusions that can be drawn about trends and dynamics in renewable energy technology deployment and their respective regional applications. But it is clear that Germany, Spain and the USA have been the global renewable energy pioneers from whom lessons can be learned in several respects. China, India and Brazil have experienced remarkable expansion in their renewables sectors over the last years. Until recently, renewable energy deployment and installed capacity were expected to continue to grow, fostered by a constant flow of investments and policy support. However, their performance has been mixed in recent years due to reduced public financial support as a result of the financial and economic crisis and, in particular, due to declining costs of renewable energy technologies that undermine the rationale for financial support (IRENA, 2013). Changes in the global PV market, for instance, have lowered module and cell production in European countries, resulting in a loss of 23,000 jobs in Germany and 20,000 in Spain. The USA also saw a decline in the share of total solar employment in manufacturing from 36% to 25% between 2011 and 2012. Meanwhile, manufacturing shifted towards Asia where almost 86% of global solar module production took place in 2012 (IRENA, 2013). Thus, countries are confronted with rising international competition in production and trade. In contrast to employment in manufacturing, employment in installation and O&M is localised and therefore less sensitive to shifts. In total, the renewable energy sector withstood the latest financial and economic crisis more successfully than other industries (IRENA, 2013). Renewable energy has become a relatively mature economic sector with steady technological progress, falling production costs and rising labour productivity.

What are the prospects for future employment in the renewable energy sector? Several editions of 'Energy [R]evolution' (Greenpeace International et al., 2012) offer global scenario projections for renewable energy employment in 2015, 2020 and 2030. Under the Energy [R]evolution scenario, global employment in renewable energy, including direct jobs in MCI, O&M, and domestic fuel supply, started at 7.9 million jobs in 2010 and will reach 12.2 million in 2015, 13 million in 2020 and 11.9 million in 2030. Employment is thus expected to grow by nearly 65% between 2010 and 2020. However, increased labour productivity outweighs additional growth in renewable energy at the end of the projection period with employment shrinking to 11.9 million jobs in 2030. It is still not clear to which extent renewable energy and low-carbon employment can go beyond fossil and nuclear fuel-based energy production, since low-carbon technologies are essentially substitutes for traditional technologies. In its Energy [R]evolution policy scenario, the study shows employment in fossil fuels and nuclear energy dropping from 14.7 million in 2010 to 11.2 million in 2015, to 9.7 million in 2020 and to 6.3 million in 2030 (Greenpeace International at al., 2012). Thus, the losses in fossil fuels and nuclear energies (–8.4 million jobs 2010/2030) far outweigh the gains in direct jobs from renewable energy production (+4.1 million jobs 2010/2030). IRENA (2013) calculates a well-performing renewable energy employment policy scenario (REmap 2030), estimating the effects of a doubling of the share of renewable energy in the global energy mix, reaching 16.7 million renewable direct and indirect jobs in 2030. It thus derives substantial growth potential for renewable energy employment within the coming decades.

4.2 Assessment of peer-reviewed studies on renewable energy employment

This section analyses the selected pool of economic impact studies on employment effects from renewable energy published in peer-reviewed journals. Well-known journals in the field of energy and climate change economics have been screened according to different keywords related to employment effects and renewable energy deployment (see Annex 2 for details). In total, 23 articles have been selected according to the criterion that a presentation of quantitative results on employment effects from renewable energy deployment must be presented, preferably using a model-based approach. The 23 selected articles (reporting date was September 2013) are clustered according to their assessment approaches. The first cluster of studies (Table 5) displays employment factors for different renewable energy technologies, but does not calculate absolute employment effects from RES deployment (studies 1–8). The second cluster of studies (Table 6 and Table 7) deals with renewable scenarios based on national or regional policy targets, investment and financing schemes. The primary focus of these studies is electricity and heat production. Most studies do not consider the transport sector and thus exclude biofuels and fuels produced from renewable energy sources such as electricity, biogas or hydrogen from their analysis, with the exception of Neuwahl et al. (2008, study 23) who assess the effects of biofuels from first and second generation fuels on the job market. However, there are no systemic approaches to renewable energy supply that integrate different energy sectors of the economy, including transportation. These may yet reveal economic or environmental synergies and should therefore be considered for future research. The selection of studies focuses on renewable energy deployment and in the majority of cases disregards any analysis of energy efficiency. Beyond these features, few common characteristics can be found. Each study develops its region-specific set of policy assumptions, using different assessment methodologies and deployment paths, so that employment effects are difficult to compare. In addition, assumptions about key data such as export demand, fossil fuel prices and technological learning curves differ substantially. In general, the majority of model-based analyses derive positive net employment effects from renewables. However, the results strongly depend on the way in which renewable energy deployment is financed. Studies that, for example, assume increasing electricity prices to be mainly incurred by households may derive negative employment effects due to income losses (study 12). Negative impacts on employment also result from increased labour taxes used to subsidise RES deployment (study 9).

The employment factors displayed in the various assessments are summarised in Table 4. As mentioned before (section 3.1), the employment factor approach can be differentiated into employment factors for different phases of the life cycle, such as R&D, manufacturing, construction/installation, O&M, that in sum results in total direct employment per MW or GW of installed capacity, or of per MWh or GWh generated electricity or heat. Employment factors differ according to labour intensity in various regions of the world. The summarised employment factors from the literature show a range of employment factors which is higher than the one applied in Greenpeace International et al. (2013, see Table 2). For instance, PV employment factors range from 28 jobs/MW to 55 jobs/MW depending on the geographical area, with Greece and the Aragon region showing the highest employment, while the latest Energy [R]evolution assessment uses an average employment factor of about 18 jobs/MW (Greenpeace International et al., 2013), which is much lower than those factors found in the literature review.

Table 4 Employment factors of PV and wind from reviewed studies

		Region	*Year of publication*	*No. of study*
		PV		
Jobs/GWh	1.03	USA and Europe	2012	1
	1.09	GRE	2011	2
	0.87	USA	2010	14
Jobs/MW	38	Aragon (ESP)	2010	4
	29	ESP	2013	7
	37.3	ESP	2008	16
	54.8	GRE	2013	18
	37–46	TUR	2011	21
	28.3	Middle East	2013	22
		Wind		
Jobs/GWh	0.2	USA and Europe	2012	1
	0.33	GRE	2011	2
	0.17	USA	2010	14
Jobs/MW	13	IRE	2007	3
	10.74	BRA	2013	6
	13.2	ESP	2008	16
	8.3	Middle East	2013	22

Source: Own representation

With respect to wind energy the array of employment factors taken from the literature ranges from 8 jobs/MW to 13 jobs/MW, which is closer to the factor applied in the Energy [R]evolution study (8.8 jobs/MW).

The analysis confirms a much more stable and uniform employment environment for wind energy than for PV, where learning has occurred much more quickly, lowering labour intensity substantially in recent years. Cameron et al. (2013) confirm that the variance of employment factors for PV is much wider than that for wind, with a range of about 7 jobs/MW to 43 jobs/MW in manufacturing and installation of PV and about 3 jobs/MW to 16 jobs/MW for manufacturing and installation in wind energy. The lower bound of the employment factors for PV is much smaller than the one taken from the literature review here and could be the result of recent studies that incorporate learning and economies of scale. Due to the dynamic context of technological development, employment factors must be interpreted as a snapshot taken within a specific setting in the process of energy transition. For example, considering the employment factor of 0.86 jobs/MW for wind energy from study 4 (Table 5) must be interpreted as an outlier with respect to the other results. The authors explain this as resulting from the particular situation in the year of investigation (2007), in which almost no installation occurred in the region of study.

In Table 6 and Table 7 studies are assembled that model net employment effects from renewable deployment. These studies therefore portray a rather conservative estimate of renewable employment in comparison to studies considering gross effects. The majority of studies show slightly positive effects on net employment, with the exception of particular forms of subsidies (studies 9 and 12) or energy strategies (study 17). When subsidies for RES are financed by labour tax or electricity tax increases, employment results happen to be negative from induced negative income effects (study 9). A negative trend in renewable employment may be the result of rising energy prices due to renewable deployment (study 12).

Studies 9 to 14 investigate employment effects in Germany. Study 10, for instance, calculates a net additional employment of between +25,000 and +180,000 in 2030 depending on assumptions about the export share: the higher the export share, the higher the resulting employment effect. Study 9 quantifies net employment of +40,000 to +250,000 in 2010 from the introduction of an environmental tax reform where revenues are used to lower non-wage-labour costs, thus benefiting the labour market. Results also vary according to different oil price scenarios, with a higher oil price accompanied by higher employment results from renewable deployment. Some studies, such as the study on Turkey (study 21) and that on the Middle East (study 22) quantify gross direct or gross direct and indirect employment effects.

A tentative conclusion can be derived from this first compilation of peer-reviewed studies on employment effects from renewable energy deployment, namely that a majority of policy scenarios show beneficial effects with respect to the labour market in terms of net employment gains. In addition to the GHG mitigating effect from switching to renewable energy production, positive economic effects in terms of employment (and income growth) may also occur if subsidy and investment policies are carefully chosen. Studies that incur the financial burden on the part of households, either through labour wage tax increases or higher electricity prices, tend to show negative net employment effects. In general, however, a detailed comparison of model results is not feasible, because scenario approaches of renewable energy deployment paths depend on a complex set of assumptions, policy scenarios and feed-back mechanisms (rising energy prices, a reduction of fossil fuel imports, a restructuring of public and private spending and technological learning curves) that differ in most of the studies. As a general rule, greater harmonisation of the methods and assumptions used to estimate renewable energy jobs would enable more accurate comparisons across different technologies and countries.

Table 5 Studies using the employment factor approach

	Author and title	Region	Time period	Methodology	Data source	Trigger/policy scenarios	Employment factors				Employment scope				
											Gross	Net	Direct	Indirect	Induced
1*	Lambert and Silva (2012)	USA and Europe	1998–2004	Review	13 reports and studies listed in Kammen et al. (2004)	-	PV	1.03 jobs/GWh	4.13 jobs/$		x		x		
							Wind	0.2 jobs/GWh	2.81 jobs/$						
							Biomass	0.21 jobs/GWh	2.75 jobs/$						
2	Tourkolias and Mirasgedis (2011)	GRE	Present	IO-model	-	National target for RES deployment into power sector: 40% in 2020. Four different scenarios w.r.t. import share, unemployment rate, decreasing investment costs for RES, and public expenditure.	Hydro	0.33 jobs/GWh			x		x	x	x
							PV	1.09 jobs/GWh							
							Wind	0.49 jobs/GWh							
							Biomass	0.80 jobs/GWh							
							Geotherm	0.24 jobs/GWh							
3*	Dalton and Lewis (2011)	IRE	2007	Comparison of installed wind capacity and jobs in wind industry in Europe and Ireland	Approx. 20–25 reports of NGO's and EU/international organisations (EU and UNEP)	Job creation by historic development of wind power installations	Wind	Onshore wind 10–16 job-years/MW (construction)	0.44–2.4 job-years/MW cumulative (O&M over lifetime)		x		x		
4*	Sastresa et al. (2010)	Aragon (ESP)	2007	Review	-	Papers	PV	38 jobs/MW	R&D:	10.25	x		x		
									Inst.:	8.12					
									O&M:	-					
							Wind	0.86 jobs/MW	R&D:	0.8					
									Inst.:	0.02					
									O&M:	0.05					
							Solar heat	43 jobs/MW (due to high rate of expansion)	R&D:	1.6					
									Inst.:	40.41					
									O&M:	-					

Note: Studies marked with *: see Annex for remarks.

Source: Own representation

Table 5 Studies using the employment factor approach (continued)

	Author and title	Region	Time period	Methodology	Data source	Trigger/policy scenarios		Employment factors	Employment scope: Gross	Net	Direct	Indirect	Induced
5	Thornley et al. (2008)	UK	-	Survey of existing plants	CHP and electricity plants	-	Biomass	1.27 job-years/GWh	x		x	x	x
6	Simas and Pacca (2014)	BRA	2010–2017	Analytical method and IO-model multiplicators for indirect employment	Personal interviews and review of onshore wind turbine's life cycle assessments	Realisation of wind energy projects expected to begin operation by 2017	Wind	Person-year-equivalents/MW Manufacture (direct/indirect): Nacelle 0.85/0.34 Rotor 1.75/0.99 Tower 0.81/0.87 Construction steel tower 6.73/0.59 O&M 0.59 Total 10.74/3.4	x		x	x	
7*	Llera et al. (2013)	ESP	2001–2010	Supply chain analysis	• Analysis of reports on activity of business associations • Trade information of companies • Surveys	No scenarios. Comparison of real observed jobs and model results for the historic period of 2001–2010	PV	Jobs/MWp	x		x		
8	Steininger and Voraberger (2003)	AUT	2020	General equilibrium model	Austrian Social Accounting Matrix	Exploiting the full supply potentials of a range of renewable energy sources until 2020 by implementing public subsidies: Renewable sources: wood, pellets, woodchips, biogas, rapeseed oil, rapeseed methyl ester	Biomass	Averages effects, jobs/GWh Single home heating – wood, pellets, woodchips 1.01 Small CHP –biogas, rapseed oil, recycled oil 0.60 Distric heating – woodchips, pellest, bark, straw 0.95 Large CHP – woodchips, bark –0.94		x	x	x	x

Note: Studies marked with *: see Annex for remarks.

Source: Own representation

Table 6 Studies on employment effects – Germany

	Author and title	*Region*	*Time period*	*Methodology*	*Data source*	*Trigger/policy scenarios*	*Employment factors*			*Employment scope*				
										Gross	*Net*	*Direct*	*Indirect*	*Induced*
9	Böhringer et al. (2013)	GER	Static year 2004	CGE	Mainly: GTAP7 2004	Policy scenarios: implementation of renewable electricity (RES-E) Subsidies financed by 1 lump-sum tax 2 labour tax 3 electricity tax 4 coal subsidy abolishment: revenue-neutral replacement of existing coal subsidies	Hydro Other RES		Results for RES-E being subsidised 100% • Lump-sum: positive employment effect, i.e. decline of unemployment rate from 10% to 9.86% • Labour tax, negative, increase to 10.28% • Electricity tax, negative for high subsidy (positive for small subsidy rate) • Coal subsidy abolishment, positive, decrease to 9.87% (negative for small subsidy rate)		x	x	x	x
10	Lehr et al. (2012)	GER	2009–2030	IO-mode PANTA RHEI	PANTA RHEI model Nitsch and Wenzel (2009)	Scenarios: • Internat. fossil fuel prices (path A, path B) • Export of PV (optimistic, moderate, max) • Investment in domestic RES according to Nitsch and Wenzel (2009): Leitszenario 2009 • Additional investment in PV (PV1, PV2)	Hydro PV Wind Biomass Geotherm Biogas Solar Heat pumps	Onshore and offshore Electricity and heat Electricity	Net employment of between +25,000 and +180,000 (optimistic export) in 2030		x	x	x	x
11	Bach et al. (2002)	GER	1999–2010	PANTA RHEI (IO) LEAN (CGE)	-	Environmental tax reform Increased fossil fuel tax, revenues are used to lower non-wage labour costs Four scenarios: low and high crude oil prices, model comparison	RES as in nine plus CSP		40,000–250,000 additional jobs in 2010 due to lower non-wage-labour costs		x	x	x	x

Note: Studies marked with *: see Annex for remarks.

Source: Own representation

Table 6 Studies on employment effects – Germany (continued)

	Author and title	*Region*	*Time period*	*Methodology*	*Data source*	*Trigger/policy scenarios*	*Employment factors*			*Employment scope*				
										Gross	*Net*	*Direct*	*Indirect*	*Induced*
12	Hillebrand et al. (2006)	GER	2004–2010	Econometric model	-	Scenarios: REF: freezes the RE status quo of 2003 S1) Expansion of RE share to 12.5% in 2010 Investment in power plants (focus on windpower) Investment in power grid, modification of power plant fleet (natural gas) Investment volume 2.6 Bn € (2004) – 1.5 Bn € (2010) • increasing electricity costs • induced negative income effects	 Hydro PV Wind Biomass Geotherm Biogas	Investment (Bn €): 2004 2006 2008 2010 0.208 0.208 0.208 0.208 0.375 0.443 0.511 0.579 1,668 1,078 0.608 0.608 0.280 0.044 0 0 0 0.016 0.028 0.021 0.020 0.056 0.055 0.063 0.050	Investment induced increase in jobs and induced job losses due to higher energy prices (in 1,000 jobs) 2004 2006 2008 2010 Investment induced 35.66 25.35 19.77 19.37 Price induced –2.3 –7.7 –15.46 –23.31 Total 32.3 17.6 4.3 –5.0		x	x	x	x
13*	Lehr et al. (2008)	GER	2004–2030	PANTA RHEI (IO) Data on RES	Central model data: • Survey of 1,100 interviews • PANTA RHEI model Central scenario Data: IEA, European Renewable Energy Council	Scenario pool: 1 Four export scenarios: Diff. export shares of RES technology (cautious, cautious optimistic...) 2 Two internat. scenarios w.r.t energy prices: • REF: reference scenario in prices (IEA) • DCP: dynamic and current policy (European Renewable Energy Council) 3 Two German scenarios: • REF: economic reference forecast by EWI/Prognos –30% (–44%) CO_2 achieved in 2030 (2050) • TOS: target-oriented scenario: reach national target of –40% (–80%) CO_2 in 2030 (2050)	Hydro PV Wind Biomass Geotherm Biogas CSP		Four gross employment results, employment in RES sectors (in 1,000) *Export scen./internat. scen./ german scen.* 2004 2010 2020 2030 Cautious/ DCP/TOS 157 244 306 333 Cautious/ REF/REF 157 161 170 180 Caut. optimistic/ REF/REF 157 170 181 197 *One net employment result* 2010 2015 2020 2030 Difference between cautious/REF/REF and cautious/ REF/TOS 55 64 74 84	x	x	x	x	
14*	Kuckshinrichs et al. (2010)	GER	2005–2007	Extended IO-model	Clausnitzer et al. (2008)	German CO_2 refurbishment programme for the years 2005–2007	Energy efficiency	Building refurbishment programme 2005–2007	Direct Empl./€ 2005 2006 2007 Invested (job-years/Mio. €) 18.3 18.4 16.4	x		x	x	

Note: Studies marked with *: see Annex for remarks.

Source: Own representation

Table 7 Studies on employment effects – other countries

	Author and title	*Region*	*Time period*	*Methodology*	*Data source*	*Trigger/policy scenarios*	*Employment factors*				*Employment scope*				
											Gross	*Net*	*Direct*	*Indirect*	*Induced*
15*	Wei et al. (2010)	USA	2009–2030	Employment factor approach combined with scenarios	15 reports and studies listed in the paper	Three energy demand scenarios: BAU (+24% energy demand), medium-EE (+12% energy demand) and 'flat energy' (+6% energy demand) Two energy production scenarios: BAU with 7.4% RES-E in 2020 and 9.1% in 2030 Policy scenario: 20% RES-E in 2020 and 30% RES-E in 2030	 Hydro PV Wind Waste Biomass Geotherm Solar CCs Energy efficiency	Job-years/GWh (direct) 0.27 0.87 0.17 0.72 0.21 0.25 0.23 0.18 0.38	Insulation of buildings	2009–2030 Medium-EE: +1.9 Mio. job-years Flat-energy: +4 Mio. job-years	x	x	x		
16	Moreno and López (2008)	ESP	2005–2010	Employment factor approach in combination with scenarios	Spanish Renewable Energy Development plan 2005–2010 (IDEA, 2005) Partly based on forecasts from 1996 (TERES II)	Scenarios (baseline-optimistic-pessimistic): Investment in RES according to Spanish Renewable Energy Development plan 2005–2010	Hydro PV Wind Biomass Biogas Solar Biofuels	18.6 (constr.) 1.4 (O&M) 34.6 (constr.) 2.7 (O&M) 13 (constr.) 0.2 (O&M) Thermal: 0.12 (constr.) 0.01 (O&M) 25 (constr.) 6 (O&M) 2.5 (constr.) 5 (O&M) 5 (constr.) 1.5 (O&M)	Five-year-period Electricity: Jobs/MW 4 (constr.) Jobs/MWp 0.14 (O&M) Jobs/MW Jobs/toe Jobs/MW Jobs/1,000m^2 Jobs/1,000t/y	+9,996–10,700 +274–587 professional jobs (high skill)		x	x		
17	Cai et al. (2011)	CHN	2006–2009	Employment factor approach (direct), IO-model (indirect employment) combined with scenarios	Governmental publications: 11th 5-year plan of developing RES in CHN, 2008, and official statistics	Policy scenarios: Power generation 2006–2009 with different power plant fleets, or 'What if the same amount of electricity was generated by large (efficient) coal power plants (LCPP) or by renewables?' Reference: Additional capacities inst.: Large Coal Power Plants (LCPP) Replacements: - Policy 1 'replace': Additional capacities inst.: LCPP Replacements: Small CPP are replaced by LCPP Policy 2 'mitigation': Additional capacities inst.: renewables Replacements: Small CPP are replaced by LCPP	 Hydro PV Wind Biomass	2006–2009 Direct / Indirect 1.95 jobs/MW (inst.) 6.1 jobs/GWh 0.5 jobs/MW (inst.) 150 jobs/GWh 0.38 jobs/MW (inst.) 21.7 jobs/GWh 0.32 jobs/MW (inst.) 51.7 jobs/GWh	Policy 1 / Policy 2 (in 1000) Direct: –559 / Direct: +76 Indirect: +~1,000 / Indirect: –599 Total: +479 / Total: –523	Policy 3 Policy 1 and 2 combined, prolongation to 2010 Total: +472		x	x	x	

Note: Studies marked with *: see Annex for remarks.

Source: Own representation

Table 7 Studies on employment effects – other countries (continued)

	Author and title	*Region*	*Time period*	*Methodology*	*Data source*	*Trigger/policy scenarios*	*Employment factors*						*Employment scope*				
													Gross	*Net*	*Direct*	*Indirect*	*Induced*
18	Markaki et al. (2013)	GRE	2010–2020	IO-model	Eurostat IO-tables of 2010	Implementation of the National Renewable Energy Action Plan of Greece: • investments of 47.9 bn € • 18% renewable energy share of final energy demand • minus 5% CO2 w.r.t 2005 • 10% biofuel share • increase of energy efficiency		Jobs/MW installed			Jobs(FTE)/ Mio. € investm.	108,000 average full time equivalents (FTE) over 2010–2020, of which 47.8% direct, 28.2% indirect, 24.1% induced	x		x	x	x
							Hydro	Small hydro (pumped-storage)	34 (40) of which…	Direct 16.2 (18.7) Indirect 11.6 (14.4) Induced 6.2 (7.1)	22.7 (21.1)						
							PV		54.8 of which…	Direct 25 Indirect 19 Induced 11	20.7						
							Wind	Onshore (offshore)	19.8 (21.3) of which…	Direct 12 (9) Indirect 9 (23) Induced 5 (13)	19.8 (21.3)						
							Biomass		109.2 of which…	Direct 59.2 Indirect 31.4 Induced 18.7	23.3						
							Geotherm		44 of which…	Direct 19.4 Indirect 15.3 Induced 9.3	20						
							Solar				18.8						
19*	Lund and Hvelplund (2012)	DEN	2010–2020	IO-model	-	24% of building stock integrated in district heat grid and equipped with heat pump. G22 net investment of 9 bn €. *Scenarios:* different combinations of technologies 1 80% (out of the 24%) district heat, 20% heat pump 2 S1 + district heat by large scale heat pumps (300–400 Mwe input) 3 S2 + 40% solar thermal energy in 90% of district heating 4 S3 + geothermal energy in comb. with waste-CHP plants 5 S4 + natural gas single boiler replaced by biomass boiler						7,000–8,000 jobs/year Positive public revenues over whole period			x	x	x
20*	Turner et al. (2013)	AUS	2010–2060	Process based model CSIRO	Australian National Accounts – Australian Bureau of Statistics	100% renewable electricity scenario: Transition to • zero-emission eletricity plants (domestically manufactured) • electric cars • increased energy efficiency • increased biomass use	Hydro PV Wind Biomass					Positive until 2030 (peak at +40,000), flattens out to zero until 2060 (positive in manufacturing)		x	x	x	

Note: Studies marked with *: see Annex for remarks.

Source: Own representation

Table 7 Studies on employment effects – other countries (continued)

	Author and title	*Region*	*Time period*	*Methodology*	*Data source*	*Trigger/policy scenarios*	*Employment factors*			*Employment scope* Gross	Net	Direct	Indirect	Induced
21	Cetin and Egrican (2011)	TUR	2010–2030	Spread-sheet model	Coefficients taken from non-peer-reviewed studies and workshops	PV roadmap for Turkey Objectives: • solar energy plants 20 MWp/a • installation of 4 GWp by 2020 • 50% of panels, cells and inverters produced locally	PV: 37–46 jobs/MWp	In detail: • Installation (34.6) • O&M (2.7) • Panel production (10) • Additional: wholesale, retail, installation (36)	Direct gross employment in Turkey in 2020 due to PV Roadmap: 177,000–220,800	x		x		
22*	van der Zwaan et al. (2013)	Middle East	2010–2050	Technology model		Installation of renewable electricity technologies until 2050 to reach a capacity of 210 GW and generate 60% of total electricity demand	Min/median/max PV: Person years/MW in • Manufacturing 3.2 / 12.6 / 19.4 • Installation 3.9 / 15.4 / 23.6 Jobs/MW in O&M 0.1 / 0.3 / 0.7 Wind: Person years/MW in • Manufacturing 2.1 / 6.6 / 12.2 • Installation 0.5 / 1.5 / 2.8 Jobs/MW in O& M 0.1 / 0.2 / 0.6 CSP: Person years/MW in • Manufacturing 2.3 / 5.1 / 18 • Installation 2.3 / 5.1 / 18 Jobs/MW in O&M 0.2 / 0.5 / 1.0		Gross employment in 2050 (median coefficients applied) 270,000 jobs of which... 155,000 direct 115,000 indirect	x		x	x	
23*	Neuwahl et al. (2008)	EU	2020	Dynamic econometric IO-model	GTAP6 EUROSTAT agricultural statistics	Scenarios (in 2020, in %): BAU/PRIMES_G1/PRIMES_G2/GRX-LC (least cost) Biofuel share: 6.9 / 15.2 / 15.2 / 12.3 Share 1st generation fuel: 80 / 33 / 33 / 54 Share 2nd generation fuel: 20 / 33 / 66 / 0 Share biofuel imports 0 / 33 / 0 / 46	Biofuels: 1st generation: Bioethanol (cereals) Biodiesel (rapeseed) 2nd generation: (lignocellulose feedstock) biodiesel (from biomass gasification)	Job effects in 2020 (in 1,000 jobs): Variant A: Subsidised biofuel blending financed by additional taxing: BAU / PRIMES_G1 / PRIMES_G2 / GRX-LC +100 / +70 / –40 / –38 Variant B: No subsidy. mandatory blending BAU / PRIMES_G1 / PRIMES_G2 / GRX-LC +73 / +182 / +20 / +38			x	x	x	x

Note: Studies marked with *: see Annex for remarks.

Source: Own representation

5 Conclusions

The review of articles from the peer-reviewed literature shows that most studies that analyse the increased introduction of renewable energy into the energy mix of different countries show positive net effects of employment creation. However, the results of the studies are difficult if not impossible to compare due to their differing assumptions, methodologies, system model borders and policy scenarios. Robust scientific evidence on net employment creation from renewable energy deployment is therefore not (yet) possible to derive. Further systematic research is required in order to validate a potential positive interlinkage of RES supply and net effects on the labour market. In particular, the analysis shows that the way in which renewables are brought into the market, i.e. via subsidies or other financial support plays a major role in determining whether employment effects are positive or negative. If, for instance, renewables are substantially subsidised and this subsidy goes to the account of significantly higher energy prices, as in some European feed-in tariff systems, the overall net impacts on the labour market may turn negative due to repercussions in demand from household budgetary constraints. But only one of these studies (no. 9) assess the role of fossil-fuel subsidy removal in order to support the role-out of RES technologies. Thus, the system borders of the modelling, i.e. whether refinancing public expenditure for renewables is recognised or not, plays a crucial role in determining employment effects.

In addition, employment effects are influenced by the technological lead of the region, which is represented in the export and import structure of the relevant renewable energy technology: the higher the export share, the higher the national employment effects in the manufacturing sector. When manufacturing takes place abroad, employment effects in the manufacturing sector are minor, with employment only occurring in O&M and, where applicable, R&D. This amount of employment may not suffice to compensate for losses resulting from crowding out in the domestic fossil fuel sector.

A shift from domestic manufacturing of renewables to manufacturing abroad (and thus import of devices) has recently been observed in the PV sector, along with employment shifts from Europe and the USA to China. Job losses in the PV sector in the EU are, however, being compensated for in the wind energy sector (EurObserv'ER, 2013). The renewable energy sector as a whole can thus be characterised as having a dynamic economic environment in terms of technological development, movements on the learning curve, costs and employment scopes.

The investigated studies almost exclusively assess ex post or ex ante scenarios in developed (OECD) countries and regions (with the exception of China). Further research is therefore required for transition and developing countries in order to validate or debunk these conclusions on a global scale.

In total, the number of employment studies on renewables remains limited. In order to draw more comprehensive conclusions, further systematic research is required, particularly with respect to the effects of

1. the different concepts on how renewables are subsidised or financially supported
2. the import and export structures of manufacturing renewables
3. different energy price developments
4. regionally distinct labour intensities of renewables in manufacturing.

A broader scope of studies with comparable structures and time horizons could help to validate what the majority of present studies suggest: net employment effects from renewable energy deployment.

Finally, it appears that there is considerable growth potential for renewables and renewable employment in a variety of markets. However, these markets must be triggered by stable and sensibly designed investment strategies, such as long-term supporting schemes (e.g. feed-in tariffs) and a global approach towards climate protection (e.g. carbon tax or cap and trade systems) in order to leverage existing opportunities from renewables.

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Notes

1 In addition to increasing the share of renewable energy supply, improving the energy efficiency is central in order to reduce greenhouse gas emissions. It is considered to be the most cost-effective way. Efficiency-induced reductions in energy consumption help to increase the share of renewables in final energy consumption.

2 This refers to the operation of renewable energy technologies. Evaluating the production process of RE is crucial to account for emissions and energy consumption during the entire life cycle of RE. For instance, photovoltaic panel production and the transformation of metallic silicon into solar silicon require energy inputs, and the panel assembling uses energy-intensive aluminium frames and glass roofing. But in total, the energy payback is positive over the life time, e.g. a modern wind turbine produces about 80 times more electrical energy than consumed in manufacturing and installation and photovoltaic systems produce about ten times more energy (Carbajales-Dale et al., 2014).

3 Other international organisations follow similar strategies. The OECD embarked on a 'Green Growth Strategy' (OECD, 2010, 2011) in order to address environmental-economic challenges. It also influenced the management of the global financial crisis and the investment programs implemented to overcome it (Jänicke, 2012; Kletzan-Slamanig et al., 2009). According to the OECD, green growth means "…fostering economic growth and development while ensuring that natural assets continue to provide the resources and environmental services on which our well-being relies" (OECD, 2011). The OECD approach also relates to the term 'planetary boundaries' in order to refer to the space in which growth must take place (Rockström et al., 2009). The Europe 2020 strategy, in turn, addresses smart, sustainable and inclusive growth (European Commission, 2010). The Asian strategy on green transition and innovation (AASA, 2011) shall be mentioned as well. All of these approaches are similar in their future strategic realignment of economic policy towards sustainability.

4 Nomenclature statistique des activités économiques dans la Communauté Européenne.

5 Induced income effects play a critical role in the literature with respect to re-spending money savings from energy efficiency gains and are known as energy rebound (Antal and van den Bergh, 2014). Re-spending from money savings may stimulate new energy uses that partly offset the original savings.

Annex 1

Remarks (Table 5)

1 RES (PV, wind, biomass) generate slightly more jobs per investment than their fossil-fuel-based counterparts (coal and natural gas). The ratio of jobs/MW decreases with installed MW.

3 Jobs/MW installed depend on import shares and the jobs involved abroad. Therefore, these numbers should be treated with some caution.

4 The paper differentiates quality of employment.

7 The life cycle approach is applied, i.e. not only manufacturing, installation and O&M, but more detail (see coefficients) applicable to each phase. This allows investigation in more detail (import/export share of elements).

Remarks (Table 6)

13 Considers available labour skills of each RES-technology. Assumed learning curves based on historical development decrease labour intensity of RES technologies over time. Results are shown for selected scenarios only.

14 External costs of CO_2 considered social benefits if mitigated.

Remarks (Table 7)

15 RES has higher coefficients (job/GWh produced). These results inevitably result in additional jobs, as no feedback through prices and income is considered.

19 The model considers tax revenue loss due to lower fossil fuel consumption.

20 The model covers physical activities of economy (steel, aluminium, concrete, plastics etc.) and environment, including natural resources (land, water, air, biomass, energy, minerals). Economic feedback effects are not covered.

22 In the scenario it is estimated that ~50% of the manufactured goods are imported over the time period.

23 Effects are marginal: +/– 300,000 jobs at a base of 200 million workforce in the EU 25 in 2001. The authors find a quasi-neutrality of net employment of the biofuel substitution policies.

Annex 2

Screened journals and keywords for article search

Screened journals	*Searched keywords*
Applied Energy	Computable general equilibrium model
Ecological Economics	Employment
Energy	Employment effect
Energy Conversion and Management	Energy efficiency
Energy Economics	Environment
Energy Policy	Green employment
Environmental and Resource Economics	Green jobs
Environmental Innovation and Societal Transitions	Input-output model
Journal of Environmental Management	Jobs
Renewable and Sustainable Energy Reviews	Renewable energy
Renewable Energy	Renewables
Solar Energy	
The Electricity Journal	

Note: Journals in which relevant articles were found are listed in bold.

Source: Own representation