Employment Effects of Renewable Energy Supply

A Meta Analysis

Policy Paper no 12

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The WWWforEurope Policy Paper series is a working paper series that is open to policy makers, NGO representatives and academics that are interested in contributing to the objectives of the project. The aim of the paper series is to further the discussion on the development of a new and sustainable growth path in Europe.

THEME SSH.2011.1.2-1

Socio-economic Sciences and Humanities Europe moving towards a new path of economic growth and social development - Collaborative project

This project has received funding from the European Union's Seventh Framework Programme for research, technological development and demonstration under grant agreement no. 290647.

Employment Effects of Renewable Energy Supply – A Meta Analysis

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April 2014

Abstract

The paper investigates a central hypothesis of the green economy concept, which states that transitioning to a low-carbon economy is justified on a sound economic basis. We analyze this hypothesis by focussing on employment effects from renewable energy deployment, based on an evaluation of 23 selected impact studies from peer-reviewed journals. The studies are categorized into two clusters, one consisting of studies that represent employment factors of specific renewable technologies, and another that compiles model-based scenario assessments on employment effects from specific renewable policies. Both clusters distinguish the applied methodologies and the type of employment effects considered – direct, indirect, induced, gross or net. Given the heterogeneity of assumptions, the results of the different studies are hardly comparable, although we find that a majority of the investigated scenarios show positive net employment effects. These results crucially depend on the financing of an RES support scheme and the global competitiveness (technological lead) for a specific technology. The positive link between renewable energy deployment and job creation is thus not straightforward, since 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. Further research is needed.

Key words: renewable energy, employment effects, green economy, climate mitigation

JEL-code: J20, Q01, Q20, Q52

Acknowledgements: The authors would like to thank Georg Licht, Kurt Kratena and Angela Köppl for their useful review suggestions, Susanne Markytan for research assistance and Astrid Nolte for language comments.

1. Introduction

The interest in analyzing employment effects and scientifically 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 acknowledgement that humanity faces severe environmental degradation based on unsustainable production and consumption patterns of modern industrialized societies. These energy and resource rich lifestyle patterns are being emulated by emerging and developing economies, namely with high economic growth rates and fast-growing populations. Correlated economic activities ranging from transportation, manufacturing and services to agriculture and mining mainly globally rely on fossil fuel combustion, generating pollution and emissions which, in sum, undermine critical ecosystem services and life-support systems. Climate change is just one key challenge humanity faces, in addition to air and water pollution, desertification, biodiversity loss, overfishing, acidification of oceans and deforestation. These environmental problems are now increasingly aggravated by the impact of anthropogenic climate change.

With respect to the labour market, Europe and the world are facing stagnating economies accompanied by 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 300 million 15-to-24-year-olds are not working (The Economist, 2013).

These socio-ecological developments suggest a mismatch with the objectives of a sustainable economy that would be characterized by environmentally benign and socially inclusive production and consumption patterns securing 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.[1] It is defined as low in carbon, resource-efficient and socially inclusive. It "…results in improved human well-being and social equity, while significantly reducing environmental risks and ecological scarcities" (UNEP, 2011). The transition towards a green economy requires public and private investments that will support a decrease in GHG emissions and pollution, enhanced energy and resource efficiency, and the prevention of biodiversity loss, as well as ecosystem services that generate growth in income and employment (UNEP, 2011). The central hypothesis of the green economy concept maintains that transitioning to a green economy has sound economic justification. Positive economic impacts from transitioning towards a low-carbon economy are important additional arguments for public engagement in long-term climate mitigation policies; however,

[1] The green economy was a focal point of the UN conference on sustainable development in Rio 2012 (Rio+20).

they have to be considered co-benefits of environmental policies and not its mayor target.

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 meta-analysis 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 may create 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, etc., are not considered in the present analysis.

The paper is structured as follows: Section 2 provides an introduction to state-of-the-art planetary boundaries research and introduces renewable energy technologies as a central strategy for mitigating climate change. Section 3 explores the concept of "green employment" and presents its central definitions. Section 4 is on renewable deployment and job creation, with section 4.1 delineating methodologies to project employment effects, section 4.2 presenting an assessment of peer-reviewed studies and their results on renewable employment, and section 4.3 summarizing studies for Austria. Conclusions are presented in section 5.

2. Planetary boundaries, climate change and renewable energy

It is now generally acknowledged that human activities have become the main driver of global environmental change, altering the stable environmental state in which humanity lived for the past 10,000-12,000 years. This new era, of which a central feature is enormous expansion in the use of fossil fuels with significant consequences for the functioning of the earth's system, is called the Anthropocene age (Steffen–Crutzen–McNeill, 2007; Rockström et al., 2009). A key challenge for humanity is to understand its own role as a dominant force in the operation of the biosphere, its resources and services derived from and produced by ecosystems, and in actively shaping socio-economic development in tune with the planet (Folke, 2012).

Rockström et al. (2009) suggest 10 planetary boundaries as an envelope for sustainability. Of these, 7 boundaries have been quantified by trying to identify thresholds which, if crossed, could generate unacceptable environmental change. These thresholds attempt to mark a safe operating space for human societies. Three of these boundaries may already have been transgressed, namely those for climate change, the rate of biodiversity loss, and changes in the global nitrogen cycle (Rockström et al., 2009, Folke, 2012).[2] For human-induced climate change there is a growing convergence towards a 2°C guardrail approach which means that the rise in global mean temperature should not exceed +2°C above the pre-industrial level. In order to stay within this threshold, Rockström et al. (2009) suggest that human changes to atmospheric CO_2 concentration should not go beyond 350 parts per million by volume (ppm), as otherwise the risk of irreversible climate change increases.[3]

A study by the World Bank (2012) provides recent scientific analysis of likely impacts associated with a +4°C warming, which is what scientists are nearly unanimously predicting will take place by the end of the century without serious emission reductions. This would result in unprecedented heat waves, severe drought, major floods in many regions and inundation of coastal cities, all having a serious impact on human systems, ecosystems and associated services. A +4°C world would also be linked with high uncertainty and new risks that threaten our ability to anticipate and plan for future adaptation. The risks and costs of the devastating economic consequences of inaction, i.e. of a business-as-usual path of energy- and resource-intensive economic growth has been stressed in several other investigations such as the IPCC 4th and 5th assessment reports (IPCC, 2007; IPCC, 2014) and the Stern review (Stern, 2007).

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[2] The remaining boundaries concern stratospheric ozone, ocean acidification, the phosphorus cycle, land use change, freshwater use, chemical pollution and interdependent boundaries (Rockström et al., 2009, Folke, 2012).

[3] The annual mean CO_2 concentration of 2013 stood at 396.48 ppm ftp://aftp.cmdl.noaa.gov/products/trends/co2/co2_annmean_mlo.txt. Reaching a +2°C path is still possible if negative GHG emissions are produced.

Renewable energy as a core strategy for mitigating climate change

Renewable energy sources (RES) and technologies play a crucial role in mitigating climate change and providing energy services such as light, cooking, space heating, mobility, communication and production processes (IPCC, 2011).[4] 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.[5] 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 2012, the worldwide renewable power capacity grew by 8.5% with respect to 2011, exceeding 1,470 GW in 2012 (REN21, 2013). Hydropower rose by 3% to an estimated 990 GW, while other renewables grew by 21.5% to exceed 480 GW. Globally, wind power accounted for about 39% of renewable power capacity added in 2012, followed by hydropower and solar PV, each accounting for approximately 26% of the added capacity (REN21, 2013). Renewables made up just over half of total net additions to electric generating capacity from all sources in 2012. Residential, industrial and commercial energy consumers are increasingly becoming producers of renewable power in a growing number of countries (REN21, 2013). 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). Thus, there is 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, a stable political framework for investments and private engagement.

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[4] In addition to increasing the share of renewable energy supply, energy efficiency reduces greenhouse gas emissions. It is supposed to be the most cost-effective way. Efficiency-induced reductions in energy consumption help to increase the share of renewables in final energy consumption.

[5] This refers to the operation of renewable energy technologies. Evaluating the production process of RE is, however, important in order to consider emissions and energy consumption during the entire life cycle. For instance, in photovoltaic panel production the transformation of metallic silicon into solar silicon is highly energy consuming and the panel assembling is characterized by the use of aluminium frame and glass roofing which are very energy-intensive materials. However, the energy pay back time is estimated to be shorter than the panel operation life time, so that photovoltaic electric production is advantageous for the environment (Stoppato, 2006).

3. Green Employment: A Concept in Transition

Given the requirement to de-carbonize the current energy system and transition to environmentally benign production and consumption patterns, and given the challenges of overcoming the economic downturn and increasing employment shares, the concept of the "green economy" has been introduced by the United Nations Environment Programme (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, 35).[6] 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 still missing. Green jobs are also not well-captured in government and other statistics, because green employment cuts across different sectors of the economy. Thus, data on green jobs is spread across different sectors of industrial classification systems, e.g. of the European statistical classification of economic activities (NACE[7]) or the North American Industry Classification System, and must be especially assembled. An example for such cross-sectoral industries is the environmental goods and services industry (Eurostat, 2009, OECD 1999) or the tourism industry (Eurostat et al. 2001).

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[6] 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.

[7] Nomenclature statistique des activités économiques dans la Communauté Européenne

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 thus to characterize 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 endeavor to find coherent measures on green employment that are universally applicable (following 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 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 environment-related technologies often labeled "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 (see 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 modeling, based on input-output tables that capture direct and indirect employment, in order to estimate net employment effects (see 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, and
- many existing jobs being redefined as greened skills, methods and profiles.

In order to be precise about the quantity of green jobs reported it should be indicated whether these relate to gross or net employment effects (see section 4 for further details). Other categorizations 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 shall be considered "green". If the additional income from induced employment is spent on energy- and material-intensive goods and services, the induced employment effect compensates environmental gains derived from direct and indirect green employment and therefore should, in principle, not be considered green ("employment-income rebound"). However, such qualitative distinctions have not yet been made in modeling green employment effects from renewable energy deployment. But 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 – van den Bergh, 2014). In this case, re-spending from money savings may stimulate new energy uses that partly offset the original savings. Another useful distinction of job categories is the stage of job creation within the life-cycle of the resource or energy saving technology. That is, whether jobs are created in R&D, production, construction and installation or in operation and management (O&M) is relevant 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/less labor intensive and results in more/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" is to place a stronger emphasis on improving resource productivity rather than labor 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, gives an overview of basic methodologies for measuring employment effects and presents a meta-analysis of peer-reviewed journal articles that analyze employment from renewable energy supply.

4. Renewable energy deployment and job creation

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 databases originating from literature by government ministries, international agencies, industry associations, non-governmental organizations, consultancies and academic institutions. According to this, the majority of renewable energy employment is concentrated in China, Brazil, the European Union, the United States and India (Table 1). These countries are the biggest manufacturers of renewable energy equipment, producers of bioenergy feedstock and installers of production capacity. However, other countries are following by boosting their investments and policies in support of renewable energy deployment, thereby creating jobs, mostly in operations and maintenance activities.

Employment trends vary across renewable energy technologies. The increase in biofuel capacity leads employment creation, in particular with respect to biomass feedstock production. Cultivation and harvesting of biomass feedstock is more labor-intensive than other technologies, however, mechanization of feedstock operations reduces related labor 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 operation and management (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, as it can boast only 37.000 jobs. Spain and the United States currently lead the market for CSP with 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. Yet the industry is expanding quickly to other parts of the world. For example, in 2012 China and the United States installed 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 area.

Table 1: Employment in Renewable Energy Globally and for Selected Countries/Regions

	EUROPEAN UNION (EU)			UNITED				
	GERMANY	SPAIN	OTHER EU	STATES	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

Source: IRENA (2013), own calculation. Data are mostly from 2009-2012, the last column is derived from the world totals of employment. CSP: concentrated solar power.

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. However, it is obvious that Germany, Spain and the United States 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 supply 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 United States 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 in O&M is localized 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 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 manufacturing, construction and installation, O&M, and domestic fuel supply, started at 7.9 million jobs in 2010, reaching 12.2 million in 2015, 13 million in 2020 and 11.9 million in 2030. Employment therefore grew by nearly 65% between 2010 and 2020. At the end of the projection period, increased labour productivity outweighed additional growth in renewable energy, which declined 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 by Greenpeace et al. (2012) shows employment in fossil fuels and nuclear energy dropping from 14.7 million in 2010 to 11.2 million in 2015, 9.7 million in 2020 and 6.3 million in 2030. Thus, the losses in fossil fuels and nuclear energies (–8.4 million jobs 2010/2030) by 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 therefore derives substantial growth potential for renewable energy employment within the coming decades.

4.1. Methodologies for projecting 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%). Projections may be assessed 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 data sets. 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 input-output (I-O) modeling, as well as methods drawing on input-output 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 electricity prices. These studies therefore emphasize 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).

However, the two approaches do not capture the economy-wide employment effects in terms of net employment. 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 summarizing 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. 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 modeling 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 2 provides an overview of the interrelations between result categories (gross, net, direct, indirect and induced) and methodologies found in the present literature review.

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. They neither cover full inter-sectoral nor income effects. Furthermore, 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 Input-Output model. This model is very adaptable and commonly used in examining every result category.

Table 2: 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 * CGE	I-O * CGE	I-O * CGE

* using specified adaptations and/or extensions (further assumptions, additional sub models and others)

** only in case w here a literature-based "indirect employment coefficient" is applied

Source: Own representation.

4.1.1. 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 and 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 one particular renewable technology may thus relate to regional considerations – that is, whether manufacturing takes place in highly industrialized 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 import structure of manufacturing. This means that countries exporting renewable technologies and components generate employment in addition to their domestic renewable energy capacity and that installed renewable capacity may not be misinterpreted as an indicator for renewable employment (IRENA, 2013). Denmark is often cited as an example, as it has a large wind turbine manufacturing sector (high employment rate) with most of the components exported. This situation significantly inflates the jobs-per-MW ratio (Lambert – 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 labour productivity. Many renewable technologies are still in an early stage of development, and therefore cost degressions and economies of scale are expected to occur in the future, resulting in lower employment factors. Table 3 provides an overview of employment factors from OECD countries applied in the Energy [R]evolution scenario (Greenpeace 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 productivity, estimates of employment factors need to be continuously revised.

Table 3: Employment factors used in global analysis

FUEL	MANUFACTURING	CONSTRUCTION & INSTALLATION	OPERATION & 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 & manufacturing)			
Solar – heat	7.4 jobs/MW (construction & manufacturing)			

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

4.1.2 Supply chain analysis

Supply chain and input-output 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 input-output analysis, because it is more of a project-specific analysis than a method for calculating single 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 modeling 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; Liera et al., 2013).

4.1.3 Input-output analysis

Input-output (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 practice of economic analysis 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. Total production of an industry derives as the sum of all inputs to other industries plus final demand, plus exports minus imports (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 10 renewable energy technologies as production vectors to the German I-O table. 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 adequately capturing of specific renewable technologies and their employment effects (e.g. PV or wind), as well as the fact that I-O modeling implicitly assumes a constant structure of the economy. In light of large economic transformations such as the energy transition, these approaches can significantly depart from reality, and therefore all quantitative results on employment figures must be interpreted with caution.

4.2. Overview of international peer-reviewed studies on renewable energy employment

This section analyses economic impact studies on the employment effects from renewable energy deployment published in peer-reviewed journals. In total, 23 articles have been selected and 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 1-7). 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 1st and 2nd 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 focusses 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 such 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 11). Negative impacts on employment also result from increased labor taxes to subsidize RES deployment (study 8).

The employment factors displayed in the various assessments are summarized in Table 4. As mentioned before (section 4.1.1), 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 summarized employment factors from the literature show a range of employment factors which is higher than the one applied in Greenpeace et al. (2013, see Table 3). 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 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 & 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 & 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 or increasing labour productivity substantially in recent years. Cameron and van der Zwaan (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 within the process of energy transition. For example, considering the employment factor for wind from study 4 (Table 5) of 0.86 jobs/MW must be an outlier with respect to the other results (Table 4). 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.

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 (2012)	USA & Europe	1998-2004	Review	13 reports & studies listed in Kammen et al. (2004)	-	PV Wind Biomass	1.03 jobs/GWh 0.2 jobs/GWh 0.21 jobs/GWh	4.13 jobs/$ 2.81 jobs/$ 2.75 jobs/$	x		x		
2 Tourkolias (2011)	GRE	present	IO-model	-	National target for RES deployment into power sector: 40% in 2020. 4 different scenarios w.r.t. import share, unemployment rate, decreasing investment costs for RES, and public expenditure.	Hydro PV Wind Biomass Geotherm	0.33 jobs/GWh 1.09 jobs/GWh 0.49 jobs/GWh 0.80 jobs/GWh 0.24 jobs/GWh		x		x	x	x
3* Dalton, Lewis (2011)	IRE	2007	Comparison of installed wind capacity and jobs in wind industry in Europe & Ireland	Approx. 20-25 reports of NGO's and EU/international organisations (EU & 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 Wind Solar Heat	38 jobs/MW 0.86 jobs/MW 43 jobs/MW (due to high rate of expansion)	R&D: 10.25 Inst.: 8.12 O&M: - R&D: 0.8 Inst.: 0.02 O&M: 0.05 R&D: 1.6 Inst.: 40.41 O&M: -	x		x		
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, Pacca (2013)	BRA	2010-2017	Analytical method & IO-model multiplicators for indirect employment	Personal interviews & review of onshore wind turbines 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 Projects/studies 0.33 Silicon 0.98 Cells 2.41 Module assembly 9.05 Solar tracker 6.37 Electr. components 2.60 Installation 6.06 Operation 1.65 Total 29.46		x		x		

Source: Own representation. Studies marked with *: see Annex for remarks.

Table 6: Studies on employment effects – Germany

	Author and Title	Region	Time period	Methodology	Data Source	Trigger/Policy Scenarios	Employment Effects			Employment scope				
										Gross	Net	Direct	Indirect	Induced
8	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) labor 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
9	Lehr et al. (2012)	GER	2009-2030	IO-model PANTA RHEI	PANTA RHEI Model Nitsch, Wenzel (2009)	Scenarios: - Internat. fossil fuel prices (path A, path B) - Export of PV (optimistic, moderate, max) - Investement in domestic RES according to Nitsch, Wenzel (2009): Leitszenario 2009 - Additional investment in PV (PV1 , PV2)	Hydro PV Wind Biomass Geotherm Biogas Solar Heat pumps	onshore & offshore electricity & heat electricity	Net employment of between +25,000 and +180,000 (optimistic export) in 2030		x	x	x	x
10	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 4 scenarios: low and high crude oil prices, model comparison	RES as in 9 plus CSP		40,000-250,000 additional jobs in 2010 due to lower non-wage-labour costs		x	x	x	x
11	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 0.016 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
12*	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		4 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	x
13*	Kuckshinrichs et. al. (2010)	GER	2005-2007	Extended IO-model	Clausnitzer (2008)	German CO_2 refurbishment programme for the years 2005-2007	Energy efficiency	Building Refurbishment programme 2005-2007	Direct Empl./€ invested (job-years/Mio. €) 2005 / 2006 / 2007 18.3 18.4 16.4	x		x	x	

Source: Own representation. Studies marked with *: see Annex for remarks.

Table 7: Studies on employment effects – other countries

	Author and Title	Region	Time period	Methodology	Data Source	Trigger/Policy Scenarios	Employment Effects	Employment scope: Gross	Net	Direct	Indirect	In-duced
14*	Wei et al. (2010)	USA	2009-2030	Employment factor approach combined with scenarios	15 Reports & studies listed in the paper	3 energy demand scenarios: BAU (+24% energy demand), Medium-EE (+12% energy demand) and "flat energy" (+6% energy demand) 2 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	job-years/GWh (direct) Hydro 0.27 PV 0.87 Wind 0.17 Waste 0.72 Biomass 0.21 Geotherm 0.25 Solar 0.23 CCs 0.18 Energy Efficiency 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, López (2008)	ESP	2005-2010	Employment factor approach in combination with scenarios	Spanish Renewable Energy Development plan 2005-2010 (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	5-year-period Hydro 18.6 (constr.) 1.4 (O&M) jobs/MW PV 34.6 (constr.) 2.7 (O&M) jobs/MWp Wind 13 (constr.) 0.2 (O&M) jobs/MW Biomass thermal: 0.12 (constr.) 0.01 (O&M); electricity: 4 (constr.) 0.14 (O&M) jobs/toe Biogas 25 (constr.) 6 (O&M) jobs/MW Solar 2.5 (constr.) 5 (O&M) jobs/1,000m² Biofuels 5 (constr.) 1.5 (O&M) jobs/1000t/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 electricty 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	2006-2009 (Direct / Indirect) Hydro 1.95 jobs/MW (inst.) / 6.1 jobs/GWh PV 0.5 jobs/MW (inst.) / 150 jobs/GWh Wind 0.38 jobs/MW (inst.) / 21.7 jobs/GWh Biomass 0.32 jobs/MW (inst.) / 51.7 jobs/GWh in 1000: Policy 1: Direct: –559; Indirect: +~1,000; Total: +479 Policy 2: Direct: +76; Indirect: –599; Total: –523 Policy 3: Policy 1&2 combined, prolongation to 2010; Total: +472		x	x	x	
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. 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: 18.8 108,000 average full time equivalents (FTE) over 2010-2020, of which 47.8% direct, 28.2% indirect, 24.1% induced	x		x	x	x

Table 7: Studies on employment effects – other countries, continued.

	Author and Title	Region	Time period	Methodology	Data Source	Trigger/Policy Scenarios	Employment Effects				Employment scope				
											Gross	Net	Direct	Indirect	In-duced
19*	Lund, 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	x
20*	Graham 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	
21	Cetin, 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	PV Wind CSP	min/median/max 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 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 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 (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 : Subsidized 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

Source: Own representation. Studies marked with *: see Annex for remarks.

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 8 and 11) 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 8). A negative trend in renewable employment may generally be derived from rising energy prices due to renewable deployment (study 11).

Studies 8 to 13 investigate employment effects in Germany. Study 9, for instance, calculates a net additional employment of between +23,000 and +180,000 in 2030 depending on assumptions about the export share. The higher the export share, the higher is the resulting employment effect. Study 8 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 overview 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 harmonization of the methods used to estimate renewable energy jobs would enable more accurate comparisons across different technologies and countries.

4.3. Studies on renewable employment in Austria

This section offers an overview of recent studies on renewable employment effects in Austria (see Table 7). The study by Haas et al. (2006, study 1) uses existing studies and own empirical data to analyse the employment effects of a broad range of renewable energy technologies for the year 2004. They derive a total gross employment of 32,700 full-time equivalent (FTE) jobs with most of the jobs (19,100) created in O&M. For the manufacturing of renewable technologies the study derives 13,600 FTE jobs.

Bodenhöfer et al. (2004, study 2) calculate a prospective scenario on feed-in tariffs for several renewable energy technologies and derive employment factors over their technical lifetime. Employment factors are quantified on a net basis, including direct, indirect and induced effects. The inclusion of indirect and induced effects explains why employment factors are much higher than those found in the study by Haas et al. (2006). One striking finding is that employment factors evaluated for PV and wind are negative. This is the result of substitution effects with fossil fuels, increased electricity prices and high import shares for wind and PV modules. The latter is responsible for a low employment rate in the manufacturing of wind turbines and PV modules in Austria. The missing employment component from manufacturing cannot therefore compensate for losses from fossil fuel substitution such that overall employment becomes negative.

A recent analysis of net employment effects by Bointner et al. (2013, study 3) evaluates the economic impacts of the effective increase in the share of renewable energy supply during the 2000 to 2011 period for Austria. The study models the economic development that would have potentially occurred if a renewable energy supply had not been further promoted. Thus, the evaluation is based on a comparison between empirical economic data of the growing share of renewables between 2000 and 2011, with a hypothetical reference scenario that simulates a slightly falling share of RES nevertheless based on rising energy demand. The development incurred 3,300 additional jobs on average per year. The calculation takes into account shrinking public spending that follows from diminished tax revenues from fossil fuel consumption, as well as from decreased household spending due to rising energy costs.

In contrast, study 4 by Kranzl et al. (2011) evaluates the total net employment potential, including direct, indirect and induced jobs of the renewable energy sector within two different time periods. Accordingly, the renewable sector accounted for 39,000 FTE jobs in 2009 and will potentially reach 50,000 FTE jobs in 2020.

The study by Hinterberger et al. (2009, study 5) builds its assessment of net employment effects upon three scenarios that investigate the effects of different renewable energy technology mixes by 2020. While the first scenario (STA) focusses on cost-effective renewable solutions, the BIO-scenario primarily investigates biomass and biogas as alternatives to fossil fuel-based energy systems. The DAM-scenario, in contrast, evaluates the effects of more costly potential technologies of the future, including PV, solar thermal, wind and geothermal technologies. The result is that the highest employment effects (19,600 FTE in 2020) are generated with the most costly technologies, followed by biomass technologies (13,900 FTE) and the cost-effective technological approach (10,100 FTE).

Moidl et al (2004, study 6) focus on economic impacts from wind energy deployment up to 2020 and 2040. They follow a mixed approach of assessing net employment, in the sense that they only consider effects from higher energy prices and not crowding out in the fossil-fuel sector. They derive positive direct employment effects of between 36,500 job-years and 15,000 job-years, depending on assumptions of energy price developments (the higher the fossil fuel prices, the higher the employment effects).

Other studies calculate employment in the Austrian renewable technology sector using surveys and questionnaires.[8] The recurrent monitoring of the Austrian environmental technology industry including renewable technologies has been carried out since the mid-1990s (Köppl et al., 2013). The latest survey derived an employment of 14,200 jobs in the manufacturing of renewable energy technologies, including intermediate supply in 2011. A study by Biermayr et al. (2012) surveys employment in 2011 with respect to biomass, photovoltaics, solar thermal and heat pumps. The employment number refers to direct employment, including manufacturing, trade and installation, and thus has a wider scope than the figure reported by Köppl et al. (2013), who monitor employment from manufacturing only. Accordingly, renewable technologies generated 27,700 FTE jobs in 2011.

In summarizing the recent literature on renewable energy employment in Austria, similar conclusions can be derived to those derived for the other country studies. Overall, employment effects from renewable energy deployment show a slightly positive trend, but this can turn negative under certain conditions – in particular if the manufacturing of renewables is mostly incurred abroad and thus cannot compensate for employment losses due to crowding out in fossil fuel-based sectors. However, the scientific basis is scattered due to the limited number of assessments and different assumptions on policy scenarios, price developments and energy mix. Diverse model system borders also make employment effects from renewable energy deployment difficult, if not impossible, to compare.

[8] As these studies do not present employment factors and are not model-based, they do not figure in the tables above.

Table 8: Studies on employment effects – Austria

	Author and Title	Region	Time period	Methodology	Data Source	Trigger/Policy Scenarios	Employment Effects	FTE / GWh		Employment scope: Gross	Net	Direct	Indirect	Induced
1*	Haas et al. (2006)	AUT	2004	IO Analysis	-Previous studies -Interviews -Previous Projects of the EEG (TU Vienna) Further details in section 4.3	Actual situation in 2004	Biomass hard Biomass liquid Biomass gaseous Geothermal Heat Hydropower (small) Photovoltaics Solar heat Heat pump Wind power	0.51 0.42 0.61 0.59 0.20 1.09 0.55 0.79 0.32	Effects in 2004 : Manufacturing 13,600 FTE O&M 19,100 FTE Total 32,700 FTE	x		x		
2	Bodenhöfer et al. (2004)	AUT	2004-2017 (respectively to technical lifetime)	IO Analysis	Calculations of authors Austrian Statistical Institute	Scenario: Implementation of feed-in-tarrifs for 7 representative installations over 13 years (time period for financial support according to the Eco Electricity Act of 2002) Considered effects: - Investments - Operation & Maintenance - purchase power loss due to higher price of electricity - crowding out of conventional power production (estimated to be marginal) - crowding out of other governmental expenditures	Biomass hard Biomass liquid Biomass gaseous Geothermal Heat Hydropower (small) Photovoltaics Solar heat Heat pump Wind power Sewage gas	0.4 - 1 2.48 2.22 0.66 -2.96 -0.25 0.11	Evaluation of technologies, no total employment effects, negative effects in PV and wind production due to losses in purchasing power as a result of higher electricity prices		x	x	x	x
3	Bointner, Raphael et al. (2013)	AUT	2000-2011	econometric simulation model "Move" Tichler (2009)	Austrian Statistical Institute Several Austrian studies	Evaluation of employment effects from RES promotion: Comparison of current state of renewables to a reference scenario without RES funding in Austria between 2000 and 2011	No technology specific coefficients, full range of renewable energy systems active in 2000 - 2011 (heat, electricity and transport fuel) considered		Scenario with increased promotion of renewabale energy: +0.05% GDP on average/year (~149 m €) +3.300 jobs on average/year		x	x		x
4	Kranzl et al. (2011)	AUT	2005-2009 and 2010-2020	IO Analysis	Austrian Statistical Institute Several Austrian studies	Evaluation of total employment in RES sector 2005-2009: Comparison of current state of renewable energy production with hypothetical scenario of no renewables (100% fossil fuel alternatives) 2010-2020: Unchanged mix of policy instruments towards renewables, increased energy prices according to PRIMES (Capros et al., 2009)	Bio-Energy systems in three Heat (Heating systems, CHP) Electricity (CHP) Green fuels		in 2009 : +39,000 FTE +1.5 bn € in net value added in 2020: +50,000 FTE +3.2 bn € in net value added		x	x	x	x

Table 8: Studies on employment effects – Austria, continued.

	Author and Title	Region	Time period	Methodology	Data Source	Trigger/Policy Scenarios	Employment Effects			Employment scope				
										Gross	Net	Direct	Indirect	Induced
5	Hinterberger, F. Stocker A. et al. (2009)	AUT	2005-2020	Macroeconomic Model with IO core	Statistic Austria E-Control Austrian Energy Agency World Model GINFORS IEA (Energy Prices)	Three Scenarios – all with increased RES Deployment but with different technology mix: STA – prefering cost effective technologies (Wind, Small Water, Biomass heat and CHP) BIO – prefering Biomass and Biogas (heat and power) DAM – prefering costly but future technologies (PV, Solar thermal, Wind and Geothermal)	Study considers Renewable heat and power technologies without transport fuels		Total Effects in 2020 compared to BAU Scenario: STA: +10.100 FTE BIO: +13.900 FTE DAM: +19.600 FTE		x	x	x	x
6*	Moidl S. et al. (2004)	AUT	2011-2020-2040	IO Analysis	Own survey among wind industry companies and supplier Statistik Austria	Two Scenarios: IGW: Strong expansion of Wind energy from 1011 MW (2009) up to 3450 MW (2020) Emplyoment effects are separated: 2011-2020 Investment phase (Construction & Installation) 2011-2040 O&M of installed plants over lifetime	 Construction & Installation O&M	FTE / MW installed 6.4-6.8 0.54	IGW Scenario : Total Gross **Positive** Effects in job-years (DIRECT) -- +17.000 by Construction & Installation (2011-2020) +11.000 by Operation &Maintenance (2011-2020) +23.000 by Operation &Maintenance (2020-2040) Total **Negative** Effects in job-years (due to higher energy prices) -- –14.500 (best case) (2011-2020) –36.000 (worst case) (2011-2020) –0 (2020-2040) wind is competitive **Net** Effects in job-years (2011-2040) -- +36.500 (best case) +15.000 (worst case)	mixed		x		

Source: Own representation. Studies marked with *: see Annex for remarks.

5. Conclusions

Based on peer-reviewed literature and other sources regarding Austria, the tentative conclusion shall be drawn that the increased introduction of renewable energy into the energy mix of different countries shows positive net effects of employment creation. However, the results of the studies, whether in terms of employment factors for different renewable energy technologies or in absolute net or gross terms, are difficult if not impossible to compare due to their differing assumptions, system model borders and modeling approaches. However, one important co-benefit of an energy transition towards a low carbon economy therefore seems to be a positive contribution to the labour market by reducing unemployment. This means there is economic justification of public engagement in renewable energy deployment.

A number of reservations about this conclusion must also be emphasized. The studies investigated almost exclusively assess *ex post* or *ex ante* scenarios in developed (OECD) countries and regions (with the exception of China). Thus, further studies are required for transition and developing countries, in order to validate or debunk these conclusions on a global scale. The analyses of the studies also show that the way in which renewables are subsidized or financially supported plays a major role in determining whether employment effects are positive or negative. If, for instance, renewables are substantially subsidized and this subsidy goes to the account of significantly higher energy prices, e.g. like with 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. Thus, the system borders of the modeling approach play a crucial role in determining the outcome for employment. In addition, employment effects are influenced by the technological lead of the region, which is represented in the share of export or import 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 operation and management (O&M) and, where applicable, R&D. This amount of employment may not suffice to compensate for losses resulting from crowding out in the 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 United States to China. According to the EurObserv'ER 2013 edition, job losses in the PV sector in the EU are, however, being compensated for in the wind energy sector. The renewable energy sector as a whole can thus be characterized as having a dynamic economic environment in terms of technological development, movements on the learning curve, costs and employment scopes.

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 subsidized or financially supported, 2) the import and export structures of manufacturing renewables, 3) different energy price developments, and 4) regionally distinct labour intensities of renewables in manufacturing. A broader scope of studies with comparable structures and time horizons could help to validate the tentative conclusions drawn from this analysis.

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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Annex

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 Paper differentiates quality of employment.

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

Remarks (Table 6)

12 Considers available labour skills of each RES-technology. Assumed learning curves based on historical developement decrease labour intenstiy of RES technologies over time. Data by German Renewable Energy Council (BEE, 2005) and "Institut für Sozialforschung und Kommunikation" (2005). Results are shown for selected scenarios only.

13 External costs of CO2 considered social benefits if mitigated.

Remarks (Table 7)

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

19 Model considers tax revenue loss due to lower fossil fuel consumption

20 Model covers physical activities of economy (steel, aluminium, concrete, plastics etc.) and environment, including natural resources (land, water, air, biomass, energy, minerals). Economic feed-back effects 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. Authors find a quasi-neutrality of net employment of the biofuel substitution policies.

Remarks (Table 8)

1 Technology coefficients are derived from Table 17 where results are normalized to a production of 2 GWh over 13 years. Here we divided by 26 (2 GWh * 13) to normalize in FTE/GWh.

6 Net calculations consider employment effects (direct, indirect and induced) of higher electricity prices, but do not cover crowding out of fossil power production and investment.

Project Information

Welfare, Wealth and Work for Europe

A European research consortium is working on the analytical foundations for a socio-ecological transition

Abstract

Europe needs change. The financial crisis has exposed long-neglected deficiencies in the present growth path, most visibly in the areas of unemployment and public debt. At the same time, Europe has to cope with new challenges, ranging from globalisation and demographic shifts to new technologies and ecological challenges. Under the title of Welfare, Wealth and Work for Europe – WWWforEurope – a European research consortium is laying the analytical foundation for a new development strategy that will enable a socio-ecological transition to high levels of employment, social inclusion, gender equity and environmental sustainability. The four-year research project within the 7th Framework Programme funded by the European Commission was launched in April 2012. The consortium brings together researchers from 34 scientific institutions in 12 European countries and is coordinated by the Austrian Institute of Economic Research (WIFO). The project coordinator is Karl Aiginger, director of WIFO.

For details on WWWforEurope see: www.foreurope.eu

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Partners

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