**Employment impacts of large-scale renewable energy expansion in China: A CGE based analysis**

**(Proposal 02/22/2017)**

#### Background

The development of renewable energy has featured prominently in China’s policy portfolio to deal with the climate challenges. The total installed capacity of renewable power in China saw booming development in the period of 12th Five-Year Plan (2010-2015), which increased from 249 GW in 2010 to approximately 499 GW in 2015. As pledged in the Intended Nationally Determined Contributions (INDC), the share of non-fossil energy in primary energy consumption will increase to approximately 15% and 20%, respectively, by 2020 and 2030. In parallel with those objectives, China’s powerful instruments such as Feed-in-Tariff (FIT) and Emission Trading Scheme (ETS) will lead to large-scale renewable power expansion in the coming decade.

Although policy makers tend to regard renewable energy as a panacea to cure more socio-economic problems than just climate change and a large numbers of studies have been working on supporting evidences for the existence of “Green Jobs” or “double dividend”, there are still deep concerns on the job destructing risks caused by the renewable policies. The concerns are supported by the standard economic theory [2], which warrants caution that stimulation on renewable energy will increase the overall energy costs and wrap the efficiency in the whole economy. China’s practice of renewable policies also affirmed the increase of energy costs since there is an additional fee for each units of consumed electricity which is used to build a specific funding to cover the subsidies for renewable power generation. The additional renewable fee was set 0.001 Yuan/Kwh in 2006 and gradually increased to 0.019 Yuan/Kwh in 2016, which is up to 4% of the sale price of electricity. As a result, the risks of job destructing should not be ignored in the process of decision-making related to renewable policies. The employment effects should be clearly identified in order to avoid unexpected social costs, especially in the context that China’s facing challenges from both climate change and unprecedented economic downturn.

In this study, we attempt to build a comprehensive method based on Computable General Equilibrium (CGE) model that incorporates detailed renewable power technologies and considers the imperfection in labor markets. We quantify the impacts on employment in the China due to the large-scale expansion of wind power and solar PV in electricity sector. We focus on answering the following questions: 1) whether China will be a net gainer or loser in terms of employment change to deploy the renewable policies; and 2) how to expand the positive or to remove the negative employment impacts through suitable design on renewable policy instruments. The remainder of the paper is organized as follows. Section 2 gives a comprehensive review of the existing studies on the employment impacts of renewable policies. Section 3 describes the model, database, and key assumptions used in the study. Section 4 provides a description of scenarios and presents the main results. Section 5 and Section 6 provides a detailed discussion, conclusion and implications respectively.

#### Literatures review

Due to the huge divergences on whether the employment impacts of renewables are positive or negative, we focus on exploring the reasons and sources for the opposite conclusions from existing studies in this section.

**Table 1** contains a list of studies reviewed, which touched on the employment impacts of renewable policies. Currently, there are mainly three approaches to study the employment impacts of renewable policies: 1) Input-output (IO) methods; 2) Analytical methods; and 3) Computable general equilibrium (CGE) methods. The advantages and disadvantages of each methodology has been well summarized in previous studies [3][4], but less attentions are paid to internal relations between the specific modeling characteristics with their conclusions on employment impacts. In fact, some assumptions in parallel with the methodologies may mislead the final conclusions. This is the major reason why some researchers are still cautious while most studies tend to believe that the renewable policies can lead to positive impacts on the employment.

**Table 1: Review of the existing literatures**

|  |  |  |  |  |  |  |
| --- | --- | --- | --- | --- | --- | --- |
| Year | Authors | Region | Research Objective | Method | Employment impacts | Employment Measurement |
| 2007 | Kuster et al.[5] | Global | Capital subsidies on renewable energy sources | CGE | Negative | Net Effects |
| 2008 | Allan et al.[6] | Scotland | Installation of marine energy capacity | CGE/IO | Positive | Gross Effects |
| 2012 | Boehringer et al. [7] | Canada | Renewable feed in tarrif | CGE | Negative | Net Effects |
| 2013 | Boehringer et al. [2] | German | Subsidies to power production from renewable energy | Theoretical model/CGE | Positive/ Negative | Net Effects |
| 2013 | Cansino et al. [8] | Spain | Increase in the production capacity of the installed biofuel plants | CGE | Positive | Unclear |
| 2013 | Rivers et al. [10] | US | Tax on fossil fuels/ subsidy on renewable power | Theoretical model/CGE | Positive/ Negative | Net Effects |
| 2014 | Allan et al. [11] | Scotland | Installation of marine energy capacity | CGE/IO | Positive | Gross Effects |
| 2014 | Cansino et al. [12] | Spain | Increase in the production capacity of installed solar parks | CGE | Positive | Unclear |
| 2008 | Lehr et al. [15] | Germany | Renewable support policy | IO | Positive | Gross Effects/ Net Effects |
| 2008 | Neuwahl et al. [16] | EU | Policy relevant biofuels penetration scenarios | IO | Neutral | Net Effects |
| 2009 | Caldes et al. [17] | Spain | Constructing and operating solar thermal plants | IO | Positive | Gross Effects |
| 2011 | Cai et al.[18] | China | Development of renewable energy | IO | Positive/ Negative | Net Effects |
| 2011 | Tourkolias et al.[19] | Greece | Exploitation of renewable energy sources in the power sector | IO | Positive | Gross Effects |
| 2013 | Oliveira et al.[20] | Portugal | Deployment of electricity from renewable energy sources | IO | Positive | Net Effects |
| 2013 | Wang et al.[21] | China | CDM projects | IO | Positive/ Negative | Net Effects |
| 2014 | Cai et al.[22] | China | Development of renewable energy | IO | Positive/ Negative | Net Effects |
| 2016 | Behrens et al.[23] | Portugal | Feed-in tariff | IO | Positive | Net Effects |
| 2016 | Guenther-Luebbers et al. [24] | Germany | Increase in biogas production | IO/System dynamics model | Positive | Gross Effects |
| 2016 | Markandya et al. [25] | EU | Low-carbon transformation | IO | Positive | Net Effects |
| 2008 | Moreno et al. [26] | spain | Renewable energy | Analytical | Positive | Unclear |
| 2010 | Llera et al. [27] | spain | Renewable energy | Analytical | Positive | Gross Effects |
| 2010 | Wei et al. [28] | US | Clean energy industry | Analytical | Positive | Net Effects |
| 2012 | Grossmann et al. [29] | Global | Large-scale photovoltaics generation | Analytical | Positive | Gross Effects |
| 2013 | Llera et al. [30] | Spanish/German | Deployment of Solar PV | Analytical | Positive | Gross Effects |
| 2015 | Ortega et al. [31] | EU | Renewable electricity deployment | Analytical | Positive | Gross Effects |
| 2015 | Sooriyaarachchi et al. [32] | Germany, Spain, et al. | Development and deployment of renewable energy and energy efficiency technologies | Analytical | Positive | Gross Effects |

On the one hand, the way employment impacts are measured may lead to the overly optimistic impression. For example, some analytical studies [15][27][28], which focus on the local and single sector issues, CGE studies [6][11] and IO studies[17][19], which focus on the regional and multi-sectors issues, measure the employment impacts using the gross effects (the total jobs being generated) versus the net effects (jobs created in one sector minus those destroyed in other sectors). Since the gross effects only include positive impacts and ignore the potential negative impacts, it is not surprise to draw a conclusion that more jobs will be created associated with the development of renewables.

On the other hand, there is a widespread “No-bounds” problem in the existing studies, especially in the IO based studies which commonly assume that supply is supposedly infinite and perfectly elastic. In this context, there are no bounds for the capacity of production so that the expansion of renewable technologies can be realized without any “opportunity costs”. As a result, the renewable technologies, which need more inputs from the value chain than the conventional generation technologies, can better stimulate the economic growth and finally create more jobs. Here comes a fantastic logic that the more expensive is a technology, the more jobs it could create. That’s why Lesser [33] criticized that the ignorance of additional costs resulting from renewable supporting measures is ‘‘free-lunch economics’’. The results from Allan et al. [11] who compare the results from IO and CGE model can also affirm the concerns.

Apart from the specific characters in parallel with methodologies, there are a few other factors that can influence the final judgements on employment impacts. The first one is the labor intensities of renewables, which are closely linked to the evaluation of direct employment impacts (jobs changes within the electricity sector). Most studies believe the renewable technologies have much higher labor intensities which means the renewable technologies need more workers to generate per unit of electric power compared with the conventional thermal power technologies.(Table) However, the data from Cai et al [18] show that the labor intensities of renewable power sectors are actually less than the coal-fired power sector. The possible reason is most coal-fired power companies are state-own and are suffering from a lower efficiency compared with the newly-built renewable programs. Based on this set of data, Cai et al[18], Wang et al[21] and Cai et al[22] conclude with the negative direct employment impacts through the indirect employment impacts (jobs changes within the whole economy) are still positive. Secondly, the gap of skill requirements has also attracted increasing interests from researchers [5][15] [22][30][31][32], which emphasizes the risks of structural unemployment. If the labor market cannot support the personal qualities requirements by the deployment of renewables, the possibility of “Green Jobs” will be much lower than the expectation. Thirdly, the technical process is also a key factor affecting the employment impact. Some researchers [3] believe the improvement of energy efficiency and the learning effects of renewable technologies will help to promote the economic prosperity and consequently create new job opportunities, while the others [32] regard technical process as a threat to jobs since it leads the production towards automation. Finally, the rigidity of labor market becomes an important source for the theoretical possibility of positive employment impacts. As Boehringer et al [2] analyzed through a theoretical general equilibrium model, there will be double dividend only if there are initial labor market rigidities, as well as suitable design on the level of subsidy rates and the financing mechanism. Even through, the employment impacts are most likely to be negative since the renewable policies increase the production costs and warp the economy away from the optimal status.

Considering both the specific characters of methodologies and other factors, it’s easy for CGE models to incorporate both the positive and negative impacts of renewable policies and present a more comprehensive picture for the policy makers. CGE models, on the one hand, can hold the advantages of IO models by capturing the universal input-output relations between renewable sectors and other sectors, while, on the other hand, enable the subtle factor substitution in the production process and income effects in the consumption process caused by the policy shocks. Based on the above analysis, this study makes effort to cover several gaps in the existing literatures related to quantifying the employment impact of China’s renewable policies.

Firstly, our study will contribute to the modeling of China CGE models through incorporating labor rigidity and involuntary unemployment. It’s hard to evaluate the employment impacts using the standard CGE models, which are built with the neoclassical closure assuming a perfect labor market and no involuntary unemployment in the economy. Under this assumption, policy shocks would not cause any impacts on the overall employment but change the allocation of labor factors among sectors.

Secondly, our analysis highlights the importance of alternative policy instruments, which are ignored in most studies, to stimulate the expansion of renewable energy. Through improving the modeling of renewable electricity technologies and policy instruments, different policy-relevant options, including feed-in-tariffs, will be analyzed in our study. In this way, the resolutions of analysis will be largely improved than just focusing on the renewable targets.

Finally, our study helps to overcome major challenge banning CGE models from high-resolution assessment on employment impacts by establishing a set of data on the sectoral employment and wage in China, which incorporates both the statistical data from a national-scale demographic census and the survey data from an independent demographic research. This study, as well as other further researches, can be well supported by our dataset.

#### Methodology and data

The employment impacts of China’s renewable policies are analyzed here using the static version of China Hybrid Energy and Economic Research model (hereafter CHEER). CHEER model is a multi-sector CGE model calibrated to the Chinese economy and is developed as an extension of the Technology-Oriented Dynamic Computable General Equilibrium model for China (TDGE\_CHN) developed in Wang et al. [34]. Compared with other Chinese CGE model, there are more detailed exposition of the production structure, greater technological detail in the electricity sector, greater details regarding the labor market and richer options on the policy instruments. 18 production sectors (**Table 2**) are aggregated from 139 original sectors in Chinese input-output table. All those adjustments make the CHEER model a good tool to quantify the employment impacts of a variety of renewable policies.

**Table 2: Sectors in CHEER model**

|  |  |  |  |  |  |
| --- | --- | --- | --- | --- | --- |
| **No.** | **Sectors** | **Abbr.** | **No.** | **Sectors** | **Abbr.** |
| **1** | Electricity | Elec | **10** | Chemical industry | Chem |
| **2** | Coal and coking | Coal | **11** | Construction Materials | CM |
| **3** | Crude oil | Oil | **12** | Iron and Steel | IST |
| **4** | Petrochemical industry | Roil | **13** | Non-Ferrous Metals | NFM |
| **5** | Natural gas | Gas | **14** | Other Energy intensive industries | EII |
| **6** | Agriculture | Agri | **15** | Other manufacturing | OM |
| **7** | Other mining | Mine | **16** | Air Transport | Air |
| **8** | Food | Food | **17** | Other Transport | Tran |
| **9** | Paper industry | Paper | **18** | Services | Serv |

###### 3.1 Model structure

The CHEER model features a detailed production structure, which is captured by nested constant elasticity of the substitution (CES) production functions. Each sector is assumed to operate under constant returns to scale and cost optimization. The essential inputs of sectoral production include material inputs that generate the input/output table, as well as factor inputs representing value added. The possibilities of substitution among different inputs are controlled by sector-specific elasticities of substitution (σ).

Production of commodities, other than electricity, is shown in **Fig. 2**. Fixed factors, such as land and natural resources, are only required in the agriculture, coal, gas, oil and mining sectors. They are treated as substitutes for other inputs to control short-term sectoral production at the top level of nested CES structure. At the lower two level, the energy factors are first combined with capital-labor aggregation, and then combined with intermediate inputs. The right-angle connections in the figure represents the fixed proportion input-output relationship, which is a special case of the CES function when σ=0.



**Fig. 2: Nested CES production structure of non-electricity sectors**

Given the paramount role of electricity sector for the employment impacts assessment of renewable policies, the representation of power production is by means of a more complex nested CES production structure (**Fig. 3**). The top nest of electricity production is a Leontief combination of power generation and power transmission and distribution. The production in power transmission and distribution is assumed to follow a fixed proportion of labor, capital and intermediate inputs. The production of power generation is competed by eight discrete technologies. Wind and solar PV are imperfect substitutes of baseload generation, due to the intermittency. Baseload generation consists of power from conventional fossil fuels (coal-fired, oil-fired and gas-fired), nuclear energy, hydro energy, and biomass with perfect substitution. In the lower nest, each technology has a similar production structure as non-electricity sectors while only non-fossil power technologies need fixed factors as essential inputs.



**Fig. 3:** Nested CES production structure of the electricity sector

Consumption in the CHEER model assumes a single representative consumer incorporating household and government. All income, including labor compensation, capital remuneration, and tax revenue, is assumed to be distributed to the representative consumer. Disposable income is then allocated between consumption of goods/services and investment. Consumption is modeled using a nested CES consumption function (**Fig. 4)**. The top level assumes a Cobb-Douglas functional form for the tradeoff between consumption goods and investment goods. This assumption is based on the Solow–Swan theory, in which saving accounts for a constant share of total income. At the second level, income is allocated to specific consumption and investment commodities assuming constant elasticities of σC and σI, respectively. At the third level, a further distinction is made between consumption of non-energy and energy commodities. This is intended to represent the idea that substitution among energy commodities is different from substitution among other consumption goods.

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**Fig. 4:** Nested CES structure of final demand

The treatment of international trade in the CHEER model follows the commonly used Armington assumption, which allows for import and export differentiation between domestic and international markets [35]. Domestic firms allocate domestic production to domestic and international markets using a constant elasticity of transformation (CET) function. Imports are substitutable with domestic goods using a CES function. Export demands and import supplies are set exogenously following the method of Wang et al. [34].

In order to take the labor rigidity into consideration, the CHEER model features a wage curve (**Equation 1**), which is used to describe the relationship between the unemployment rate and real wages in this model. and represent the unemployment rate after and before shock, respectively, while and represent the real wage. β is the core parameter in this equation and reflects the unemployment elasticity of the real wage. According to Blanchflower and Oswald (1995) [36], β is approximately -0.1 for any region or country. With the wage curve, the labor market may exhibit frictions with initial unemployment. The CHEER model further considers the inter-sectoral wage differentials and labor’s imperfect movement across sectors. Constant elasticity of transformation (CET) functions are used to allocate the total labor supply among sectors. The equilibrium wage rate is determined by the labor market clearing condition equating labor supply and demand.

 **(1)**

Assumptions on factors other than labor are more straightforward. Both fixed factor and capital are modeled to be perfectly mobile across sectors and are controlled by supply functions with constant elasticity.

###### Chinese sectoral employment dataset

In order to match with data requirement of CGE model, the objective of this section is to establish a dataset on the sectoral employment and wage in China. The available data sources include: 1) Chinese 6th population census [37], which is made in 2010 and provides the quantity of employment of different labor types in each sector; 2) Chinese Household Income Project (CHIP) [38], which is a household survey hold by Beijing Normal University with 26527 samples and provides the average wage for each labor type; and 3) Chinese 2012 Input-output table [39], which provides the total value of labor compensation in each sector. Based on the above data sources, up to 28 labor types by gender (male/female), by region (urban/rural), and by educational level (unlettered, elementary school, middle school, high school, junior college, regular college, postgraduate) can be identified. The wage data is shown in **Table 3**.

**Table 3:** Average wage for different labor types in China

|  |  |  |  |  |  |  |  |  |  |
| --- | --- | --- | --- | --- | --- | --- | --- | --- | --- |
| **No.** | **Gender** | **Region** | **Education** | **Wage**  **(Yuan)** | **No.** | Gender | **Region** | **Education** | **Wage (Yuan)** |
| L1 | Male | Urban | unlettered | 23431 | L15 | Female | Urban | unlettered | 14356 |
| L2 | elementary school | 26275 | L16 | elementary school | 18451 |
| L3 | middle school | 34098 | L17 | middle school | 23097 |
| L4 | high school | 39976 | L18 | high school | 31570 |
| L5 | junior college | 47648 | L19 | junior college | 36160 |
| L6 | regular college | 57187 | L20 | regular college | 46625 |
| L7 | postgraduate | 93353 | L21 | postgraduate | 68316 |
| L8 | Rural | unlettered | 17891 | L22 | Rural | unlettered | 12910 |
| L9 | elementary school | 21849 | L23 | elementary school | 16950 |
| L10 | middle school | 28150 | L24 | middle school | 20751 |
| L11 | high school | 30022 | L25 | high school | 23483 |
| L12 | junior college | 35971 | L26 | junior college | 29295 |
| L13 | regular college | 38878 | L27 | regular college | 33715 |
| L14 | postgraduate | 47189 | L28 | postgraduate | 28733 |

Theoretically, the relationship between labor compensation and employment quantity is shown as **Equation 2**. represents the compensation for labor *l* in sector *i*; represents the average wage for labor *l* in sector *i*; and represents the quantity of labor *l* in sector *i*.

 **(2)**

Only can be directly grasped from the available dataset, while further works are needed to estimate the sectoral wage, , and sectoral labor compensation . Following the method used in Perter (2016) [41] for electricity data, we define a targeted matrix，X={}, where represents the targeted compensation for labor *l* in sector *i*. In order to get X, we first build an original matrix A={} based on the available data (, , ). represents the total value of labor compensation for sector *i*, which can be captured from Chinese 2012 Input-Output table. represents the employment quantity of labor *l* in sector *i*, which can be captured from the 6th population census. represents the average wage for labor *l*, which can be captured from 2013 Chinese Household Income Project (CHIP). In this way, the estimation of sectoral wage is converted to the optimal problem minimizing the difference between matrix A and matrix X under several constrains. The definitions of and are shown as followed.

 **(3)**

 **(4)**

In the definition of , the first item represents the relative wage rate of labor *l* to the average wage of the overall labors, while the second item represents the average wage in sector *i*. Here is a key assumption that the relative wage rates of specific labor types to the overall labors are the consistent among sectors.In order to avoid the problem of scope inconsistency caused by different data sources, the micro survey data are only used to calculate the relative wage rates instead of absolute values. The optimal problem can be represented as followed:

 **(5)**

S.t.  **(6)**

The objective function is built following the RAS method, which is a well-known method for data reconciliation. The constraint is used to keep the consistency between the sums of compensation for each labor type with the overall labor compensation in IO table. Through the above processes, we can get the targeted matrix X with sectoral labor compensation as well as balanced sectoral employment and sectoral wage for each labor type. In order to simplify the analysis, the 28 labor types are finally aggregated into two groups, skilled and unskilled, based on the education level in this study.

In order to distinguish the characters of different power generation technologies, the employment data of electricity sector are further disaggregated. Similarly, we first calculate the relative labor intensity based on the direct employment factors from Cai et al (2011) [18] and the share of labor skills based on the GTAP-Power data [41]. Assuming the wage of each labor type is constant, the employment quantity of each technology can be estimated. The above data are presented in **Appendix A**.

###### 3.3 Measurement of employment effects

Benefit from the abundant information provided by the CGE model, higher resolution of employment effects can be distinguished and measured. For each sector, as is shown in **Equation 7**, the labor demand () is determined by sectoral output () and labor intensity ().

 **(7)**

Accordingly, the measurements of employment impacts in existing literatures are different mainly in the range of sectoral coverage, as well as the assumptions on the reactions of sectoral output and labor intensity to the policy shocks. In this study, we mainly distinguish the following three layers of employment effects associated to the expansion of renewable power.

Firstly, the direct employment effect (DEE) can be calculated assuming changes only occur in the specific renewable sector due to the expansion of renewable power while labor intensities are hold constant.

 **(8)**

Secondly, the indirect employment effect (IEE) can be calculated assuming changes only occur in the electricity sectors due to the replacement of renewable power while both the labor intensities and total power generation are hold constant.

 **(9)**

Thirdly, the total employment effect (TEE) can be calculated assuming changes occur in the whole economy due to the general equilibrium interactions, while both the labor intensities and sectoral outputs will change endogenously.

 **(10)**

###### 3.4 Other data and parameter

The CHEER model is calibrated to the 2012 input-output (I-O) table published by China’s National Bureau of Statistics (CNBS) [39]. Data on energy consumption are collected from the 2012 energy balance table [40]. The initial unemployment rates are calculation also based on the 6th national population census in China [37], which are 4.8% for the skilled labor and 2.7% for the unskilled labor.

The majority of the substitution elasticity parameters are taken from TDGE\_CHN, with necessary updates according to a recent review of the literature [42][43] (**Table 4**). Other important data related to the description of scenarios will be presented in the following section.

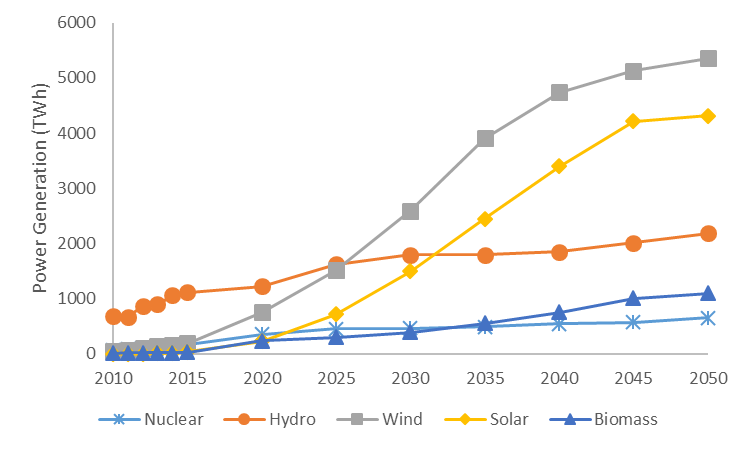
**Table 4: Core substitution elasticity parameters in CHEER model**

|  |  |
| --- | --- |
| **Parameter** | **Value** |
|  | 1 |
|  | 0.5 |
|  | Elec-0.81, Coal/Air/Tran/Serv-0.80, Oil/Gas-0.82, Roil-0.74,Agri/Mine-0.68, Other-0.94 |
|  | 0.5 |
|  | Coal-0.7, Oil/Mine -0.6, Gas-0.5, Wind-0.25, Solar/Biomass-0.2, Hydro-0.039, Nuclear- 0.025 |
|  | 0.25 |
|  | 0.3 |
|  | 0.4 |
|  | 0.25 |
|  | 1.5 |

#### Scenarios and Results

###### 4.1 Scenarios definition

We develop a Business-As-Usual (BAU) scenario and two policy scenarios in this study. The policy scenarios include (i) Feed-In-Tariff financed by additional electricity consumption fee (ECF) and (ii) Feed-In-Tariff financed by lump-sum tax (LST). The BAU scenario is constructed as a baseline for the analysis and there are no additional policies. The approach assumed in the ECF scenario is the current financial mechanism used in China, while LST provide another well-known financial option.



**Fig. 1: Historical and projected trends of non-fossil power generation in China**

In 2012, the base year of our model, power generation of wind and solar PV were 103 GWh and 3.6 GWh, respectively. Research from the National Development and Reform Commission of China (NDRC) [1] showed that the renewable power is estimated to account for as much as 85.8% of the total power generation in 2050, most increase of which comes from wind power and solar PV (**Fig.1**). Accordingly, wind power and solar PV are simulated in this study separately for each financial mechanism to assess the employment impacts of their expansion. The expansion targets are set experimentally ranking from 1 GWh to 25 GWh and the FIT level will change endogenously in each scenario. All scenarios are briefly summarized in **Table 5.**

**Table 5:** Scenario description

|  |  |  |
| --- | --- | --- |
| **Scenarios** | **Description** | **Targets** |
| BAU | Business-As-Usual | N/A |
| ECF | FIT financed by electricity fees | Power generation from renewable sources increase from 1 GWh to 25 GWh |
| LST | FIT financed by lump-sum tax |

###### Major results

This section reports results for all simulation scenarios. Our presentation of results is split into two sections. First, we present results on the direct employment effects (DEEs) and indirect employment effects (IEEs), which reflects the employment impacts of wind power and solar PV in a hypothetical linear economy. Second, we present results on total employment effects (TEEs) across the policy scenarios, which takes all the general equilibrium interactions into accounts.

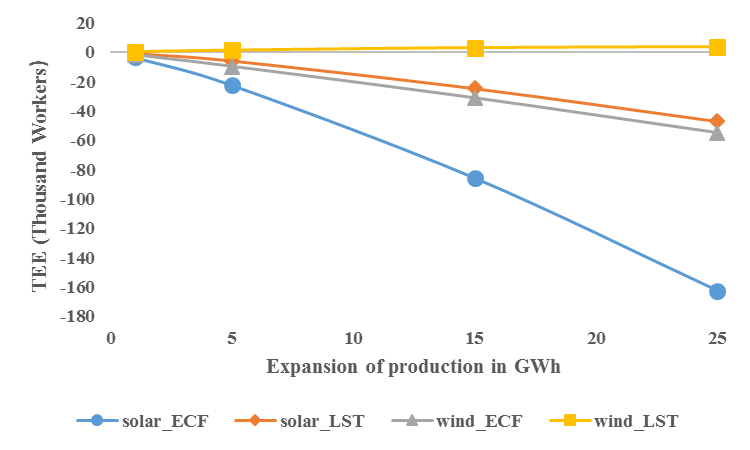
1. Direct employment effect (DEE) vs indirect employment effect (IEE)

Through **Equations (8)–(9)** and the data estimated in **Section 3.2**, the DEE and IEE of wind power and solar PV expansion in China are calculated. Since the labor intensity is hold constant, both the DEE and IEE are linearly linked to the scale of power generation. Different financial mechanisms don’t make any changes here. The DEEs per GWh of annual power generation from wind power and solar PV in China are fixed at 138 and 181 workers, respectively. Comparatively, the coal power generation technology has much larger DEE (481 workers per GWh), which is 3.5 times of wind power and 2.7 times of solar PV. One of the possible reasons is that wind and solar technologies are more technically concentrated and with higher value-added than the coal power generation technology. Considering the major role of coal power in China, it’s not surprised that both IEEs per GWh of annual power generation from wind power and solar PV are negative, which are 371 and 328 workers respectively. However, it doesn’t mean an actual job loss considering the increasing scale of power generation, but means a downward pressure on the average labor intensity in electricity sector if the power mix is switched towards wind power and solar PV. Anyway, it’s not a good news for the policymakers who are expecting for the “Green Jobs”.

1. Total employment effect (TEE)

The TEE of wind power and solar PV expansion in China are calculated based on the simulation results from CGE model. Since the economy is under equilibrium condition in the business-as-usual scenario, the subsidy rates are expected to increase to stimulate more power generation from wind power and solar PV. In the supply side, the subsidies will push the upward sloping electricity supply curve rightwards and decrease the price for power producers. Associated with the decreasing price, the production levels of other technologies are sacrificed due to their competition for electricity supply. In the demand side, the costs for renewable subsidies are paid by the electricity consumers in the ECF scenario, while the costs are shared by the whole economy in the LST scenario. As a result, the ECF approach will move the downward sloping electricity demand curve leftwards much significantly than the LST approach. The new equilibrium levels of production and price in the electricity sector are determined by the effects from both supply and demand sides, which will further affect the production level of other sectors in the economy.

In the ECF scenario, the TEEs caused by the expansion of wind power and solar PV are negative in all central cases and the negative TEEs are growingly significant as the increase of production level (**Fig. 5**). To be more specific, the loss of employment can be as much as 42 and 162 thousand workers in the whole economy to realize 25 GWh more power generation from wind power and solar PV, respectively. This effect caused by the increase of electricity prices for consumers, which are 1.1% and 4.2% beyond the initial BAU level in the 25 GWh cases if the subsidies for wind power or solar PV are financed by an additional electricity fee, can be decomposed into two sub-effects. The first one is to switch the usage of electricity to other inputs including the labor due to the substitution possibilities. Although the switch is not significant, it can be observed by through the change of labor intensities. Compared with the initial level, the largest increase of labor intensity occurs in coal mining sector, which is 0.8% and 1.5%, respectively, in the case of 25 GWh expansion of wind power and solar PV. The second one is to reduce the level of sectoral production due to the higher production costs, which is also affirmed by the simulation results. In the coal mining sector, the production levels are 0.84% and 1.54% below the initial level in the case of 25 GWh expansion of wind power and solar PV, respectively. As a consequence, the strength of later sub-effect exceeds the former one and lead to the negative TEEs.



**Fig. 5: TEEs caused by the expansion of wind power and solar PV in China**

In the LST scenario, where the financial mechanism for renewable FIT is switched from the electricity consumption fees to the lump-sum tax, the TEEs can be largely reduced in all the cases. Particularly, the TEEs caused by the expansion of wind power are positive in the LST scenario, which means there are as larger as 3.76 thousand more job opportunities if 25 GWh more power are generated from wind technology (**Fig. 5**). Although the change of electricity prices for consumers, which decrease 1.2% and 0.5% below the initial level in the cases that 25 GWh expansion of wind and solar PV are financed by the lump-sum tax, is still the major driver for the occurrence of TEE, the influence mechanisms are not as straightforward as in the ECF scenarios. From the perspective of production level, lower electricity price will encourage the production in other sectors, while the burden shared to cover the subsidies works in the opposite direction. As for the labor intensity, there are no universal rules for the change in different sectors, which is mainly due to their different weights in the costs structure of wind power and solar PV. According to the simulation results, the expansion of wind power in the LST scenario increase the levels of production in all the sectors, which dominates the creation of new jobs. However, for the expansion of solar PV in the LST scenario, the levels of production in most sectors decrease and lead to the negative TEE finally.

#### Discussion

**5.1 Does** **“double dividend” occur between renewable energy and employment?**

The results presented in this study shows there are no certain judgements on the occurrence of “double dividend” between renewable energy and employment. The conclusions are highly dependent on the species of renewable energy, the financing mechanisms for renewable subsidies and the scopes of employment impacts.

If we only focus on the wind power and solar PV industries, the pleasant conclusions can be drawn without any doubts. The more renewable power is generated; the more jobs are created. However, as stated above, it works only in the hypothetical scenario where there are no bounds for the capacity of production and the expansion of wind power and solar PV would not cause influences on other sectors in the economy. If only the focuses are moved from wind power and solar PV industries to the whole electricity sector, the “double dividend” disappears suddenly. It’s more like the actual cases that the expansion of renewable power is at the expense of conventional fossil generation technologies. Unfortunately, the labor intensities of coal-fired power generation technology, which dominates the electricity sector, are much higher than wind power and solar PV in China. As a result, the conclusions are absolutely opposite under different scopes of measurement.

From the perspective of the whole economy, which fully takes into accounts the scarcity of production factors and the costs of renewable subsidies, the influences are exerted to a much larger scope. Although the GDP is still costed, there are net job gains in the whole economy if the expansion of wind power is financed by the lump-sum tax instead of the electricity consumption fee. It means the job loss in electricity are covered by the prosperous in other sectors due to the lower electricity price. As a result, the answer to the question is “YES”, but only under some strict conditions.

**Table 6: results on employment effects**

|  |  |  |  |
| --- | --- | --- | --- |
| Unit:  Thousand workers | DEE | IEE | TEE |
| **solabor\_ECF** | 4.53 | -8.20 | -162.62 |
| **solabor\_LST** | 4.53 | -8.20 | -47.01 |
| **wind\_ECF** | 3.44 | -9.29 | -54.75 |
| **wind\_LST** | 3.44 | -9.29 | 3.76 |

**5.2 Wind power or Solar PV? What’s the difference?**

Due to a higher labor intensity, solar PV has better performances in both DEE and IEE though the advantages are not so significant. Since most “green jobs” hunters pay their attentions mainly to the renewable and electricity industries, policy makers who take DEE and IEE as core indicators are likely to give a higher weight to solar PV in the renewable strategy.

However, the facts that solar PV is much expensive than wind power and requires a higher subsidy rate to cover its costs are ignored in the judgement based on DEE and IEE. The level of Chinese feed-in-tariff in 2016 ranges from 0.44 to 0.60 Yuan/KWh (0.06 to 0.09 dollar/KWh) for wind power and 0.80 to 0.98 Yuan/KWh (0.12 to 0.14 dollar/KWh) for solar PV. As a result, per GWh expansion of solar PV requires approximately twice as much subsidies as wind power. It can largely explain why the conclusions are inverted in the analysis based on TEE no matter the subsidies are financed by the electricity consumers or by the whole economy.

The first implication behind those findings is that solar PV is not as a good as wind power from both the perspectives of economic efficiency and employment synergies. The other one is the possibility of “Green jobs” increase along with the decrease in the production costs of renewable technologies.

**5.3 Electricity consumption fee or lump-sum tax? How to finance the renewable power?**

As mentioned, additional electricity consumption fees are the current finance mechanism to support the subsidies for renewable technologies. It’s consistent to the “polluter pays principle”, which partly internalizes of external costs caused by the pollution from electricity consumption. However, the analysis in this study shows that electricity consumption fee is not a good choice when pursuing “green jobs”. The tradeoff between environmental and economic efficiency is a twice-told story. However, the policy makers should be more cautious to the choice of financial mechanism when the subsidies of renewable energy are regarded as a job creation engine. In case that there are high and persistent unemployment, the lump-tax should be a better mechanism to finance the renewable subsidies.

#### Conclusion and implication

Our analysis of the expansion of renewable power in China suggests there are no certain conclusions on the occurrence of “green jobs”. The judgments are highly dependent on the species of renewable energy, the financing mechanisms for renewable subsidies and the scopes of employment impacts. From the perspectives of the whole economy, the conditions for “green jobs” are quite strict. Only the lump-tax financed expansion of wind power can create more jobs, while the results from most other cases are quite adjective.

This study contributes to the literature by analyzing the employment impacts of renewable expansion in China. Through the comparison between different financial mechanisms for renewable FIT, the potential trade-off between “polluter pays principle” and employment concerns is revealed. Although the synergy between renewable and employment does occur in some cases, it’s hard to maximize the environmental efficiency and employment co-benefits at the same time. It’s the opinions of the authors that renewable energy should not be regarded as

the roles for renewable energy should not be unlimited expanded. In the case of China, the employment impacts of large scale expansion of renewable energy should be well assessed to avoid unexpected social costs. However, the major drivers would stay in the concerns on environmental issuses.

#### Appendix A. Data on Chinese sectoral employment and wage in 2012

Table A1：Chinese sectoral employment and wage in 2012

|  |  |  |  |  |
| --- | --- | --- | --- | --- |
| **Sector** | **Skilled Labor** | | **Unskilled Labor** | |
| Employment Quantity (Thousand People) | Annual Wage (Yuan/Person) | Employment Quantity (Thousand People) | Annual Wage (Yuan/Person) |
| Elec | 1450.2 | 112761.8 | 2480.5 | 79323.4 |
| Coal | 573.1 | 173625.5 | 4576.8 | 115713.0 |
| Oilgas | 419.1 | 165925.4 | 695.6 | 117170.8 |
| Roil | 222.1 | 179664.7 | 347.9 | 125579.9 |
| Gas | 148.0 | 49998.4 | 346.8 | 34716.5 |
| Agri | 7081.4 | 26637.9 | 329439.3 | 15514.2 |
| mine | 232.4 | 206741.7 | 2118.0 | 132384.3 |
| Food | 1032.8 | 120163.3 | 8218.3 | 62994.8 |
| Paper | 208.3 | 70189.2 | 1980.9 | 47840.4 |
| Chem | 372.9 | 100010.5 | 1338.7 | 66630.0 |
| CM | 243.4 | 92135.5 | 2109.0 | 62466.3 |
| IST | 359.9 | 71652.0 | 1510.9 | 48782.7 |
| NFM | 195.3 | 162855.2 | 839.4 | 111736.7 |
| EII | 2567.1 | 122948.2 | 20209.6 | 66568.5 |
| OM | 11598.1 | 82219.8 | 109573.8 | 43356.7 |
| Air | 279.8 | 132826.2 | 183.4 | 90458.0 |
| Tran | 2270.7 | 64571.2 | 22039.2 | 36050.8 |
| Serv | 55969.5 | 94689.5 | 127397.6 | 36303.8 |

Table A2：Employment quantity of disaggregated electricity sectors in 2012

|  |  |  |  |  |  |  |  |  |  |
| --- | --- | --- | --- | --- | --- | --- | --- | --- | --- |
| Unit: Thousand People | T\_D | Coal\_Power | Gas\_Power | Oil\_Power | Nuclear | Hydro | Wind | Solar | Biomass |
| Skilled Labor | 526.5 | 659.2 | 11.3 | 1.3 | 8.1 | 224.6 | 5.2 | 0.2 | 13.7 |
| Unskilled Labor | 900.6 | 1127.6 | 19.3 | 2.2 | 13.9 | 384.1 | 9.0 | 0.4 | 23.4 |

#### Reference

1. National Development and Reform Commission of China (NDRC). China 2050 High renewable energy penetration scenario and roadmap study: executive summary. Retrieved September 2015, from 〈http://www.efchina.org/Attachments/Report/report-20150420/China-2050-High-Renewable-Energy-Penetration-Scenario-andRoadmap-Study-Executive-Summary.pdf〉; 2015. [in Chinese].
2. Boehringer, C., A. Keller and E. van der Werf, Are green hopes too rosy? Employment and welfare impacts of renewable energy promotion. ENERGY ECONOMICS, 2013. 36: p. 277-285.
3. Lambert RJ, Silva PP. The challenges of determining the employment effects of renewable energy. Renewable and Sustainable Energy Reviews. 2012;16:4667-4674.
4. Berck P, Hoffmann S. Assessing the employment impacts of environmental and natural resource policy. ENVIRONMENTAL & RESOURCE ECONOMICS. 2002;22:133-156.
5. Kuster R, Ellersdorfer I, Fahl U. A CGE-Analysis of Energy Policies Considering Labor Market Imperfections and Technology Specifications. 2007. p.
6. Allan GJ, Bryden I, McGregor PG, Stallard T, Swales JK, Turner K, et al. Concurrent and legacy economic and environmental impacts from establishing a marine energy sector in Scotland. ENERG POLICY. 2008;36:2734-2753.
7. Bohringer C, Rivers NJ, Rutherford TF, Wigle R. Green Jobs and Renewable Electricity Policies: Employment Impacts of Ontario's Feed-In Tariff. B.E. Journal of Economic Analysis and Policy. 2012;12.
8. Cansino JM, Cardenete MA, Gonzalez-Limon JM, Roman R. Economic impacts of biofuels deployment in Andalusia. RENEW SUST ENERG REV. 2013;27:274-282.
9. Rivers N. Renewable energy and unemployment: A general equilibrium analysis. RESOURCE AND ENERGY ECONOMICS. 2013;35:467-485.
10. Allan GJ, Lecca P, McGregor PG, Swales JK. The economic impacts of marine energy developments: A case study from Scotland. MARINE POLICY. 2014;43:122-131.
11. Cansino JM, Cardenete Flores MA, Gonzalez-Limon JM, Roman R. The economic influence of photovoltaic technology on electricity generation: A CGE (computable general equilibrium) approach for the Andalusian case. ENERGY. 2014;73:70-79.
12. Lehr U, Nitsch J, Kratzat M, Lutz C, Edler D. Renewable energy and employment in Germany. ENERG POLICY. 2008;36:108-117.
13. Neuwahl F, Löschel A, Mongelli I, Delgado L. Employment impacts of EU biofuels policy: Combining bottom-up technology information and sectoral market simulations in an input–output framework. ECOL ECON. 2008;68:447-460.
14. Caldés N, Varela M, Santamaría M, Sáez R. Economic impact of solar thermal electricity deployment in Spain. ENERG POLICY. 2009;37:1628-1636.
15. Cai W, Wang C, Chen J, Wang S. Green economy and green jobs: Myth or reality? The case of China's power generation sector. ENERGY. 2011; 36:5994-6003.
16. Tourkolias C, Mirasgedis S. Quantification and monetization of employment benefits associated with renewable energy technologies in Greece. Renewable and Sustainable Energy Reviews. 2011;15:2876-2886.
17. Oliveira C, Coelho D, Pereira Da Silva P, Antunes CH. How many jobs can the RES-E sectors generate in the Portuguese context? Renewable and Sustainable Energy Reviews. 2013;21:444-455.
18. Wang C, Zhang W, Cai W, Xie X. Employment impacts of CDM projects in China's power sector. ENERG POLICY. 2013;59:481-491.
19. Cai W, Mu Y, Wang C, Chen J. Distributional employment impacts of renewable and new energy–A case study of China. Renewable and Sustainable Energy Reviews. 2014; 39:1155-1163.
20. Behrens P, Rodrigues JFD, Bras T, Silva C. Environmental, economic, and social impacts of feed-in tariffs: A Portuguese perspective 2000-2010. APPL ENERG. 2016;173:309-319.
21. Guenther-Luebbers W, Bergmann H, Theuvsen L. Potential analysis of the biogas production - as measured by effects of added value and employment. J CLEAN PROD. 2016;129:556-564.
22. Markandya A, Arto I, González-Eguino M, Román MV. Towards a green energy economy? Tracking the employment effects of low-carbon technologies in the European Union. APPL ENERG. 2016;179:1342-1350.
23. Moreno B, López AJ. The effect of renewable energy on employment. The case of Asturias (Spain). Renewable and Sustainable Energy Reviews. 2008;12:732-751.
24. Llera Sastresa E, Usón AA, Bribián IZ, Scarpellini S. Local impact of renewables on employment: Assessment methodology and case study. Renewable and Sustainable Energy Reviews. 2010;14:679-690.
25. Wei M, Patadia S, Kammen DM. Putting renewables and energy efficiency to work: How many jobs can the clean energy industry generate in the US? ENERG POLICY. 2010;38:919-931.
26. Grossmann W, Steininger KW, Schmid C, Grossmann I. Investment and employment from large-scale photovoltaics up to 2050. Empirica. 2012;39:165-189.
27. Llera E, Scarpellini S, Aranda A, Zabalza I. Forecasting job creation from renewable energy deployment through a value-chain approach. Renewable and Sustainable Energy Reviews. 2013;21:262-271.
28. Ortega M, Río PD, Ruiz P, Thiel C. Employment effects of renewable electricity deployment. A novel methodology. ENERGY. 2015;91:940-951.
29. Sooriyaarachchi TM, Tsai I, El Khatib S, Farid AM, Mezher T. Job creation potentials and skill requirements in, PV, CSP, wind, water-to-energy and energy efficiency value chains. RENEW SUST ENERG REV. 2015;52:653-668.
30. Lesser J. Renewable energy and the fallacy of ‘green’ jobs. The Electricity Journal 2010;7:45–53.
31. Wang K, Wang C, Chen J-N. Analysis of the economic impact of different Chinese climate policy options based on a CGE model incorporating endogenous technological change. Energy Policy. 2009; 37:2930-2940.
32. Armington, Paul S. A theory of demand for products distinguished by place of production. IMF Staff Papers. 1969; 16:159–78.
33. Blanchflower D. and Oswald A., 1995. An Introduction to the Wage Curve, The Journal of Economic Perspectives, 9153-9167.
34. National Bureau of Statistics (NBS), 2011a. Tabulation on the 2010 population census of the People's Republic of China. http://www.stats.gov.cn/tjsj/pcsj/rkpc/6rp/indexch.htm (accessed 2016.10).
35. China Institute For Income Distribution, 2013. Chinese Household Income Project (CHIP). <http://www.ciidbnu.org/chip/index.asp>. (accessed 2017.03).
36. National Bureau of Statistics (NBS), 2012. China input–output tables 2010. http://data.stats.gov.cn/ifnormal.htm?u=/files/html/quickSearch/trcc/trcc01.html&h=740 (accessed 2016.10).
37. National Bureau of Statistics (NBS), 2011b. 2010 China Energy Statistical Yearbook. China Statistics Press, Beijing, China.
38. Peters J.C., Hertel T.W. Matrix balancing with unknown total costs: Preserving economic relationships in the electric power sector[J]. Economic Systems Research, 2016, 28 (1): 1–20.
39. Sue Wing I. The synthesis of bottom-up and top-down approaches to climate policy modeling: Electric power technology detail in a social accounting framework. Energy Economics. 2008; 30:547-573.
40. Chen Y-H-H, Paltsev S, Reilly JM, Morris JF, Babiker MH. The MIT EPPA6 Model: Economic Growth, Energy Use, and Food Consumption. MIT Joint Program on the Science and Policy of Global Change. Cambridge, Massachusetts, USA. 2015.