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Jobs Impact of Green Energy

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Jobs Impact of Green Energy
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ABSTRACT: This brief paper accompanies the Green Energy and Jobs tool, which is a simple excel-based tool to estimate the job-creation potential of greening the electricity sector. Specifically, it calculates the net job gains or losses from increasing the level of energy efficiency, and from increasing the share of clean and renewable electricity generation in the total electricity output mix. The tool relies on estimates of job multipliers in the literature, and adds evidence from firm-level data on the job-intensity of different energy sources. The paper illustrates applications of the tool using data from the IEA's Sustainable Development Scenario compared to business-as-usual. This tool is intended to help country teams engage further on climate change issues in bilateral surveillance.

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Introduction

This brief paper accompanies the Green Energy and Jobs tool,[1] which is a simple excel-based tool to estimate the job-creation potential of greening the electricity sector. Specifically, it calculates the net job gains or losses from increasing the level of energy efficiency (EE), and from increasing the share of clean electricity options in the total energy mix. This tool is intended to help country teams engage further on climate change issues in bilateral surveillance and may serve as a useful framework for discussion of green transition and renewable energy with country authorities.

A key feature of this template is its simplicity, and flexibility. While it is only designed to calculate job creation in the electricity sector, it may be combined with additional information on GHG emissions, and investment costs of different electricity generation technologies, to build a richer narrative around climate objectives and policies in bilateral surveillance. For instance, starting with a certain country level GHG emissions target in pursuit of climate goals, this tool may be used to assess the potential contribution of the electricity sector towards that goal; and assess the costs and benefits, including the likely jobs impact of alternative electricity sector policies, and the associated investment requirements.

The aim of this note is to (i) highlight the assumptions of the template, (ii) discuss options for adjusting its application to specific circumstances, and (iii) provide an illustration of its application to a particular country case. Section I discusses the structure of the template and some of the key assumptions. Section II discusses potential adjustments to the default settings of the template, in particular regarding job multipliers, based on evidence from both firm level micro data and from recent macro level data on selected countries for the electricity sector. Section III illustrates the application of the template, taking the case Brazil's Sustainable Development scenario for electricity generation relative to the BAU, as well as some user-specified applications that reflect alternative assumptions about job-multipliers, and about potential future configurations of the electricity mix. The section also offers a comparison of the magnitude of employment generation in particular with the IEA's Sustainable Recovery (2020) estimates.

Section I: Structure of the template

The excel-based tool provides a quick comparison of employment outcomes under a business-as-usual (hereafter referred to as "BAU") electricity generation profile against alternative profiles with different levels of total generation and different shares of "clean" and "dirty" electricity in the total. This tool was originally created by Wei, Patadia, and Kammen (henceforth WPK; 2010) for application to the US.[2] It has been adapted and extended for use by other countries. The tool is simple to use. Country teams need only supply projections of aggregate and component-wise electricity generation from 2020 onwards under current assumptions (the BAU baseline). The shares of renewables (including solar photovoltaic (PV), solar thermal, wind, biomass, small hydro, geothermal, and other renewable sources), low-carbon (i.e. conventional or large hydro and nuclear), and fossil fuel (coal, gas, petroleum, and other fossil fuels) generation in the BAU can serve as a reference point for alternative user-specified (hereafter referred to as "User") scenarios with lower aggregate generation, and bigger shares of green or low-carbon electricity in total generation, for example. The template also accepts inputs for carbon capture and storage targets, which can be expressed as a share of coal-based electricity

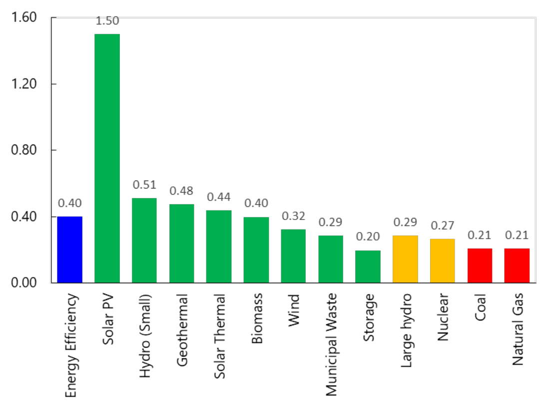
[1] This tool is available internally for download on the Climate Change Knowledge Hub on Knowledge Exchange.

[2] The tool can be downloaded from https://rael.berkeley.edu/project/green-jobs/

production that is subject to this technology. If some technologies are not yet operational but are expected to come onstream in the future, the user can also specify the starting year for such technologies.
For a few select countries (Brazil, India, China, Russia, South Africa, Japan, and the US) the aggregate and component-wise electricity generation profiles under BAU; under stated policies as of 2018 (hereafter referred to as “SPS”); and under a profile consistent with achieving SDGs (hereafter referred to as SDS), are available from the IEA. These data are available for the years 2018, 2030, and 2040. For simplicity, annual values are linearly interpolated. These may be easily updated based on more recently policy changes or commitments.
In the simplest application, the data inputs required for this template are just the projections for electricity generation in aggregate and the shares from different fuel sources (fossil fuel, low-carbon, renewables etc.). Such data may be sourced from power sector strategy documents or other official publications, which may include both BAU and alternative scenarios highlighting different policy objectives, including climate-related ones.

Job multipliers: The default point estimates of job multipliers are from WPK (2010), drawn from numerous studies analyzing job creation from the various energy sources. These studies cover not only the US, but also European countries. The multipliers template measure both the *direct* and *indirect* job creation linked to installing and operating electric capacity. To define terms, the *direct* multipliers capture jobs generated in the execution of projects, including design, manufacturing, construction, installation, operation, maintenance, and other directly related jobs (including the supply and processing of fuel for fossil-fuel based generation). *Indirect* multipliers capture upstream job-creation linked to the supply chain; for instance upstream jobs engaged in the manufacture of inputs needed to make solar panels; and downstream jobs related to (say) distribution of electricity. In the case of EE, the multiplier also captures *induced* jobs, due to additional spending out of household savings from energy-efficiency. The construction, installation, and manufacturing (CIM) jobs occur up-front in the investment cycle, whereas the operation and maintenance (O&M) jobs occur over the lifetime of the utility. Thus, the multipliers are expressed in levelized terms, spreading out the employment creation over the typical project lifecycle.

Figure 1. Job elasticities (Direct + Indirect)
(Job-years per GWH)



Source: Kammen, Wei, and Patadia (2010)

Figure 2. Total person-years/GWh by type of energy
(thousand job-years/GWh)

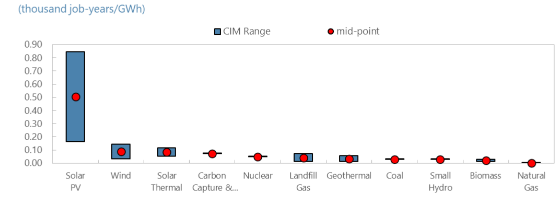


Figure 3. Total person-years/GWh by type of energy
(thousand job-years/GWh)

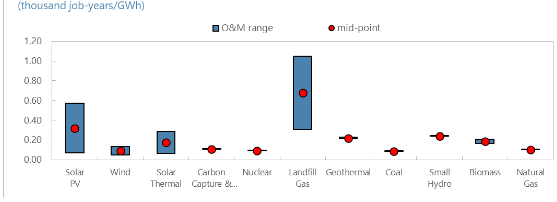


Figure 1 shows the total multiplier point estimates by technology, expressed as job-years (1 job-year is 1 FTE job of 1-year duration) per annual gigawatt-hours (GWH) of capacity.[3] In the default settings, the job-multiplier of solar photovoltaic-based electricity generation is the largest, followed by other renewable-based technologies. Among conventional energy sources, large hydro power and nuclear-based generation have

[3] 1 GWH = the flow of 1 gigawatt of electricity in 1 hour. 1 gigawatt (GW) = 1 billion watts. 1 megawatt = 1 million watts.

larger job-multipliers as compared to coal and natural gas, which are among the smallest.[4] This suggests that increasing the renewable share of generation will contribute net jobs. However, the range of estimates for solar photovoltaic technology is also sizable (Figure 2, 3).

Units of measurement: The template calculates employment in terms of job-years per gigawatt-hour (GWH) of generation capacity (or generation "saved" by EE). A typical project technical report may enumerate CIM and O&M jobs created per megawatt of peak rated ("nameplate") generation. Moreover, CIM jobs occur earlier in the investment cycle and last for the duration of putting the investment in place, while O&M jobs last over the lifetime of the utility. Making these jobs that occur at different points in the utility's lifetime comparable involves "levelizing" them, with a few simple steps (see a sample calculation in Annex Table A1).[5]

Calculating jobs. Once an overall generation growth path and the shares of individual components in electricity generation is set, the annual job-flow is calculated for direct and indirect jobs and added up to calculate total annual job flows. A couple of points are worth mentioning: (i) While there are no restrictions placed on entering the shares of different technologies in total generation, it is useful to bear in mind technological constraints—grid quality, storage, transmission issues, etc. when constructing alternative scenarios. As each country is likely to face a unique set of technological constraints, a feasible "green" mix of electricity would ideally reflect inputs from local experts. As an example, in a "green" alternative scenario, users may wish to reduce the share of fossil fuel-based generation, including from coal and natural gas, and increase the share of solar generation. Some natural gas-based generation may be desirable in such a scenario to deal with intermittency of supply for solar (and wind-based) power (see IMF WEO Chapter 3, October 2020). (ii) To the extent that electricity output in the alternative scenario is below what is generated in the baseline, it is assumed to be achieved due to improvements in EE. In contrast, no efficiency gains accrue if generation in the alternative scenario exceeds that in the BAU baseline, but no efficiency losses are imputed either.

Section II. Adjusting the multipliers

The default multipliers are set at the mid-point of these ranges and were initially derived for the US, and country teams may be interested in adjusting these multipliers to reflect local information from technical reports and input-output information (for the indirect multipliers). Given potential changes in technology over time, updating the multipliers with recent and local information as available is useful. A recent IRENA (2019) report provides some estimates of direct and indirect employment for some key renewable energy sources for a selected set

Table 1. Additional estimates of job elasticity

	World	Brazil	China	India	US	WPK 2010 1/
Thousands of jobs (2017-18)						
Solar PV	3605	15.6	2194	115	225	
Hydropower 2/	2054	203	308	347	66.5	
Wind	1160	34	510	58	114	
Solid biomass	787	…	186	58	79	
GWH of capacity (2018)						
Solar PV	4213416	18203	1533139	237631	450487	
Hydropower	11344369	915098	3085810	438718	900936	
Wind	4933506	129935	1617664	309124	827096	
Solid biomass	842898	127014	110420	88683	89031	
Total elasticity (jobs/GWH)						
Solar PV	0.86	0.86	1.43	0.48	0.50	0.79
Hydropower	0.18	0.22	0.10	0.79	0.07	0.15
Wind	0.24	0.26	0.32	0.19	0.14	0.17
Solid biomass	0.93	…	1.68	0.65	0.89	0.21

Statistcs, and authors' calculations. 1/ Wei, Patadia, and Kammen (2010). 2/ including large and small hydropower; direct jobs only.

[4] See also "Low carbon jobs: The evidence for net job creation from policy support for energy efficiency and renewable energy," UKERC 2014, for a review of studies on this subject.

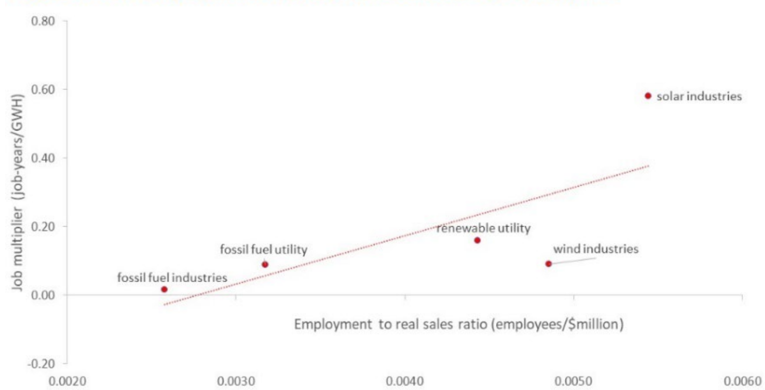
[5] This amounts to smoothing the flow of jobs over the utility life-cycle. This abstracts from transition-related issues, e.g., dealing with worker availability and skills issues that might be more pressing in the initial ramp-up of green energy capacity. However, the smoothing may also be thought of as an on-going energy sector transition, rather than all at once.

of countries (Brazil, China, India, US).[6] Combining these estimates of total employment and IRENA data on generation capacity by different technologies, we can derive another set of indicative total multipliers (Table 1). We observe that these multipliers are at the lower end of the range of implied for the US in the estimates by WPK (2010). We also observe a sizable multiplier for solar PV in China, reflecting the dominance of China in the manufacturing of solar photovoltaic equipment, accounting for more than 60 percent of the global production of cells and modules (IRENA 2019).

Some evidence from firm-level data. We also examine what firm level data can tell us about relative job-intensities of the different technologies. Worldscope data on global listed firms includes detailed business classification making it possible to identify firms with narrowly defined areas of operation, such as manufacturing of renewable energy equipment (separately for wind, solar thermal, solar photovoltaic, geothermal, etc.), services related to renewable energy, biofuel production, coal industries, oil and gas, heavy electrical machinery, renewable-based and fossil fuel-based electric utilities, etc. However, the coverage of firms each disaggregated type of activity in the dataset can be quite variable, and firms don't uniformly and routinely report employment figures.

Figure 3 shows the correlation of the computed employment to real sales (CPI deflated) for firms in selected renewable (solar photovoltaic, wind) and fossil fuel activities (including production of systems and equipment, mining, exploration, and other related services including transportation), and for renewable and fossil-fuel based utility companies; and the corresponding *direct* CIM and O&M job multipliers for solar photovoltaic, wind, and coal and natural gas (average) that are embedded in the template. As the figure shows, the employment intensities and job multipliers reasonably well correlated, giving some confidence that firm level data can provide a useful guide to adjust these job multipliers.

Figure 3. Firms' employment-sales ratio and estimates of job multipliers



Source: Wei, Kammen and Patadia (2010) for job multipliers, Worldscope database for firms' employment-sales ratios, and authors' calculations. Note: For solar and wind industries, figures show the average of the range of estimated direct CIM job-multipliers for wind and solar photovoltaic electricity generation, and corresponding employment-sales ratios for firms in the wind and solar photovoltaic systems and equipment activity according to Worldscope classification. For fossil fuel industries, the figures show the average of the range of estimated direct CIM multipliers for coal and natural gas-based electricity generation, and corresponding employment-sales ratios for firms in fossil fuels exploration, production, marketing, transporation, and related equipment and services activities. For fossil fuel (renewable) utilities, the figures show the average of the estimated O&M job multipliers for coal and natural gas (renewables)-based electricity production, and corresponding employment-sales ratio for fossil fuel (renewnable) utility companies.

The analysis below may be used as suggestive guidance for the direction of adjustment of the default job for countries other than the US, noting that the coverage across countries is not even in Worldscope data. A magnitude of adjustment is not provided here as the units of measurement are not easily expressed in job-years per GWH as required by the template. Note that this is not an exhaustive set of employment intensities, unable to cover direct and indirect CIM and O&M job creation for every technology in view of data availability, but provides some guidance on some key technologies: (i) CIM jobs in solar PV and wind technology; (ii) coal-related jobs; and (iii) O&M jobs in fossil fuels as compared to key renewables.

(i) CIM jobs in solar PV and wind technology. For the direct effect of *manufacturing* in key renewables, we show the median employment/sales ratio for China, India, US, and rest of the world (Table 3),expressed in terms of employees per $1 million in real sales. We find that the ratio for solar PV is in China higher relative to

6 Renewable Energy and Jobs, Annual Review, IRENA 2019.

the US, and lower in India and ROW. For wind, the ratio is higher in India, about the same in China, and lower in ROW relative to the US.[7] As these ratios are purely for manufacturing activity, they do not consider the job intensity of the construction and installation work, which may be more labor-intensive in countries like China and India. This suggests that in China, the *direct* CIM job multiplier related to solar PV may be higher than the point-estimates of the template suggest, and similarly in the case of wind energy in India.

Table 2. Renewables manufacturing job-intensity (employees/$'000 sales)

	China	India	US	ROW
Solar PV				
Median	7.1	2.8	5.4	2.5
1st quartile	5.7	…	4.0	2.0
3rd quartile	8.9	…	9.7	3.7
Wind				
Median	5.4	8.1	5.6	2.4
1st quartile	4.8	…	4.1	1.9
3rd quartile	6.4	…	8.4	3.7

Source: Worldscope database; and authors' estimates.

It is harder to draw comparisons for indirect multipliers from Worldscope as the data are not suited to trace out upstream and downstream linkages. Typically, input-output tables do not distinguish between renewable and non-renewable energy sectors, making indirect effects hard to calculate. Country teams may confer with local experts to adjust indirect multipliers. The default setting in the jobs template is that indirect multipliers are 90% of the magnitude of the direct multiplier, and given the larger magnitudes of the direct multipliers for renewables, the indirect multipliers are also larger. Research shows that the upstream energy intensity (carbon footprint) of solar, wind, and nuclear technology per kilowatt-hour of electricity generation is much lower than fossil fuels and large hydropower.[8] This would be consistent with greater use of labor (in place of energy) in renewable industries, implying potentially larger upstream (indirect) job effects compared to fossil fuel industries.

Table 3. Coal sector job-intensity (employees/$'000 sales)

	China	India	US
Median	24.0	10.0	2.1
1st quartile	17.0	0.9	1.3
3rd quartile	35.2	35.1	4.4

Source: Worldscope database; and authors'

(ii) The effect on coal-related jobs. A key difference between renewables-based and fossil fuel-based electricity generation is the importance of mining (fuel extraction and processing) in the latter, which is known to be a sizable employer in both China and India. Worldscope coal sector data shows that for both countries, coal jobs are much more employment intensive than they are in the US (Table 4). This should serve as a caution against assuming small direct multipliers for fossil fuel-based generation.

Table 4. Utilities job-intensity (employees/$'000 sales)

	China	India	US	ROW
Fossil fuels				
Median	7.7	3.0	1.4	1.7
1st quartile	2.5	1.3	1.2	1.2
3rd quartile	11.5	4.7	1.7	3.6
Renewables				
Median	10.0	4.4	1.4	2.2
1st quartile	4.0	3.6	0.2	1.2
3rd quartile	14.6	7.8	2.5	5.5

Source: Worldscope database; and authors' estimates.

(iii) O&M jobs in fossil fuels and key renewables. Worldscope data can also provide some comparative evidence on O&M jobs linked to renewables, using data on electricity utilities. Table 5 shows that for both China and India, renewables-based utilities are more employment intensive than fossil fuel-based ones;

[7] The ROW group in this sample mainly includes other advanced economies.

[8] https://www.carbonbrief.org/solar-wind-nuclear-amazingly-low-carbon-footprints, Pehle et al. (2017).

moreover both types are more employment intensive than US firms. This is significant, as the long-lived component of the job-creation from investment in renewable power relates to O&M jobs, and this evidence suggests that renewable technology could enhance the supply of longer duration jobs.

In summary, the foregoing analysis points to relatively high job multipliers in renewables, especially solar PV in key emerging economies. It also cautions against under-estimating job-losses linked to cutting fossil fuel generation, and the usefulness of supplementing the default estimates in the template with more recent and more granular local information.

Section III. An application to Brazil

In this section we provide a snapshot of results from applying the template to Brazil, one of countries for which we have IEA data on electricity generation profiles under BAU, SPS, and SDS. We show the impact of increasing the share of renewable energy, and of reducing overall energy consumption. In addition, we show some alternative scenarios deploying adjusted job multipliers, and making alternative assumptions about the ambition of the SDS targets. The **Summary** sheet of the template generates charts that summarize the assumptions and job-creation results once the user selects the country and the scenario.

- In the baseline, Brazil has a renewable-based generation share of 21.5 percent in 2020, and a high share of low carbon generation (62.5 percent), due its vast conventional hydropower capacity. Thus relative to the BAU, the SDS scenario achieves a greener profile by reducing the share of fossil-fuel based generation by more than 9¼ percentage points by 2040, and by increasing EE, as shown by the lower growth rate of electricity generation over 2020-2040 (Fig A1, Annex). In the baseline, aggregate generation increases by more than 67 percent over 2020-2040, and by about 40 percent in the SDS, resulting in 19 percent lower electricity generation in 2040 in the SDS as compared to BAU.
- Within the increased share of renewables in the SDS in 2040, the share of wind and solar PV is broadly similar to their share within renewables in the BAU (Fig A2, Annex).
- The template calculates net jobs are expressed in job-years, and the flow of related to the level of generation capacity and energy efficiency gains may be cumulated each year over the over the 20-year horizon. We show the cumulative net jobs relative to BAU for both the SDS, and the SPS, which reflects country energy sector policy announcements up to 2018 (Fig A3, Annex). Under SDS, there are more 500,000 cumulative net jobs over 2020-2040. The SPS leads to 300,000 cumulative net jobs over this period, as it has a less ambitious increase in the share of renewables by 2040 relative to BAU (4¼ percentage points), and a less aggressive gains in EE.
- Net jobs may also be disaggregated by the contribution of each source (Fig A4, Annex). A significant contribution to the job creation under SDS is from EE, followed by solar PV and wind energy. On the other hand, reduction in generation from conventional hydropower (reflecting the sizable cut in total generation) and from fossil fuel-based power leads to net job losses in these sectors.

User scenarios. We now illustrate an application of the template employing a purely user-specified scenario. We consider the two main case types. In case 1 we show the implications of adjusting the multipliers to the values suggested in Table 2, comparing the SDS. In case 2, we construct a scenario with user-specified assumptions about overall generation growth and the share of renewables distinct from the SPS and SDS. In particular we consider in the case of Brazil relatively less EE compared to the SDS, but a more aggressive increase in the share of renewables, doubling the share in total generation by 2040 compared to the BAU.

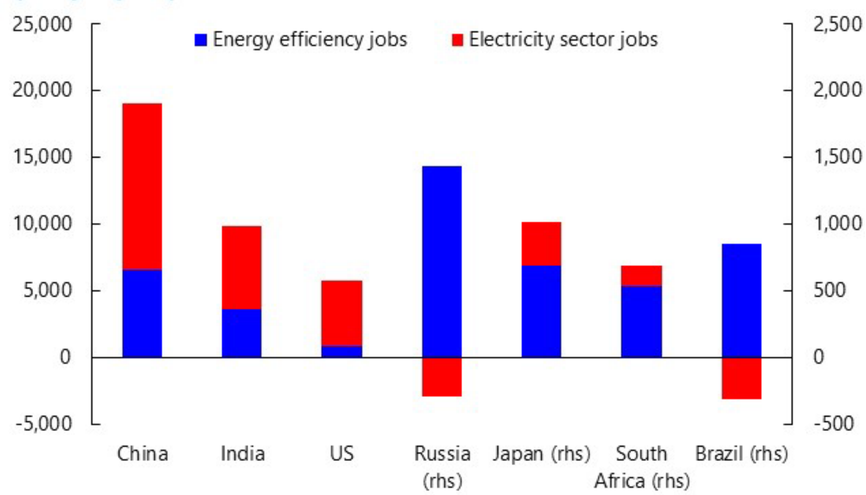
Case 1: We illustrate the impact of replacing the original job multipliers with those in Table 2 above on the gross annual flow of jobs under the SDS (the gross flows are preferable in this case rather than net as the BAU job estimates would also shift with the changed multipliers). For Brazil, the table indicates total multipliers for solar PV = 0.86, wind = 0.26, and hydro (conventional and small combined) = 0.22 jobs per GWH. Assuming that total multiplier = direct(1+indirect), and the value for indirect = 0.9, we obtain direct multipliers for 0.45, 0.14, and 0.12 for solar PV, wind, and hydro (small and conventional) respectively. These are lower than the default values. Not surprisingly, gross jobs are lower as a result (Fig A5, Annex). In countries where the share of solar PV is assumed to rise more aggressively than in Brazil, the impact would even more significant.

Case 2. In this case, we construct a scenario that differs from the SDS by assuming a smaller reduction in total electricity generation, and a larger increase in the share of renewable subcomponents (Table A1, Annex). Note that this is for illustrative purposes only. A large reduction in the share of conventional hydropower in favor of more non-hydro renewables may not be feasible in Brazil; but on the other hand, a very substantial cut in total generation as envisaged in the SDS may also appear too optimistic. The scenario shown here is only intended to illustrate the impact of taking an alternative “green” path that eliminates coal-based generation and increases the share of renewables much more than in the SDS, rather than assuming large EE gains. Indeed, though in the case of Brazil the SDS offers a guide to potentially feasible alternatives, for countries lacking IEA data on the SDS, such scenarios would ideally be constructed in consultation with the relevant policy makers and sector experts, and grounded in cost-benefit assessments of the alternatives.

We show the cumulative net job impact assuming the original KWP multipliers (Fig A6, Annex). From a job perspective, this alternative strategy does about as well as the SDS, relying on more biomass and nuclear-based generation, relying less on reduced electricity output, while also substantially reducing fossil-fuel based generation (and eliminating coal entirely).

Comparative estimates. Applying this template to all countries for which we have IEA’s Sustainable Development scenario data, under default multipliers, yields an estimated 14.6 million cumulative net job-years related to energy efficiency jobs, and another net 23.4 million cumulative job-years related to the electricity sector (Figure 4). These 7 countries account for 50 percent of world GDP (2019, PPP terms). Scaling up the SDS globally may roughly double these job estimates, or about 76 net million cumulative job-years over a 20-year period. Assuming a 20-year tenure per job, this would amount about 3¾ million additional jobs relative to the baseline, roughly 0.1

Figure 4. Cumulative job creation 2020-40 under Sustainable Development ('000 job-years)



percent of the world's labor force.[9] In comparison, the IEA estimates that the infrastructure spending needs to put the world on a net-zero emission path by mid-century are about $10 trillion over the next decade.[10] Taking the job multipliers from the IEA's Sustainable Recovery (2020) plan as a rough guide,[11] this would translate into about 90 million *gross* cumulative CIM jobs, and an additional 5 million job-years related to permanent (O&M) jobs over this period. The template estimates 76 million *net* cumulative job-years over a 20-year period (the gross figure would be higher), which is in the same order of magnitude as the IEA's green investment needs-implied figure.

A few caveats. It is also important to note the limitations of this tool. The template does capture net job effects accounting for job losses relative to BAU in, for example, fossil fuel sectors. However it does not consider the macroeconomic "cost" in terms of aggregate employment and output of the policy changes that bring about the new equilibrium energy mix, such as the imposition of carbon taxes, or costly borrowing to finance green investment. It ignores the impact of the policy mix, including due to effects on overall energy prices. These would be important factors to consider in devising the input parameters for the template. A second important issue to consider is that while renewable power is more job-intensive, it may not produce jobs offering the same wages as conventional power. According to estimates for the US, for example, fossil-fuel and nuclear energy jobs pay more than renewable sector jobs on average, though renewable jobs are competitive with the national median wage.[12] Evidence from Worldscope data also suggests that fossil fuel sector jobs can be among the highest paying in some countries.[13] At the same time, evidence also suggests that extension of small scale/decentralized renewable energy may offer opportunities to boost jobs offering higher than the national median wage, for example in India.[14] Thirdly, there can be considerable heterogeneity in what the same over-arching policy translates to at the country level. For instance, energy efficiency in advanced economies refers more to building retrofits, which are job-intensive, but in emerging economies, this could relate to reducing industrial energy use, which may come at the expense of jobs. Fourth, it should be noted that the template does not account for job-leakages in manufacturing. Countries that lack the necessary industrial base would likely import the renewable energy and energy efficiency capital goods in the transition. Thus, the default CIM multipliers may be on the high side; or the template may be better suited for countries that have some capacity to produce green capital goods domestically. Finally, it is useful to keep in mind that the purpose of renewable energy and energy efficiency investments is primarily to reduce GHG emissions and steer the world economy away from the harmful effects of climate change. Its motivation is not in the first instance related to employment generation; but which under certain conditions, net job creation could be a beneficial side effect of the transition.

[9] CIM jobs that occur up-front will of course not last the lifetime of a utility, but new capacities are expected to be created continuously over time rather than in one shot, enabling a translation of job-years to jobs.

[10] G20 Note "Reaching Net Zero Emissions," IMF 2020.

[11] The Sustainable Recovery plan envisages spending $1 trillion each year for 3 years on green infrastructure, generating 27 million *gross* CIM job-years cumulatively over 3 years globally (or about 9 million jobs of 1-year duration per year), and 0.5 million permanent (O&M) jobs. Back of the envelope, energy-related spending worth $10 trillion over the decade, for meeting net-zero goals, would translate into 90 million gross CIM job-years, and 5 million gross permanent (O&M) job-years over a decade.

[12] For the US, one study indicates that median green sector wages are about the same as those in the fossil fuel sector across all related activities, though fossil-fuel based *generation* jobs pay more, and nuclear generation more still, and require higher qualifications, than green generation. See "Clean Jobs, Better Jobs," https://e2.org/wp-content/uploads/2020/10/Clean-Jobs-Better-Jobs.-October-2020.-E2-ACORE-CELI.pdf

[13] See "Employment Effects of Environmental Policies," IMF WP 2021/140].

[14] See "Powering Jobs Census 2019: The Energy Access Workforce," July 2019.

Summary. This short paper accompanies the Renewable Energy and Jobs template. The template is simple tool designed to illustrate job-creation under different electricity generation scenarios, putting together estimates of job multipliers linked to different energy sources with projections of electricity generation over 2020-2040. The tool may be easily adapted to reflect updated and local information on the electricity sector. It may be combined with information on electricity sector emissions, and investment costs, to structure a discussion on climate policy around emission reduction targets, and the role of the electricity sector, examining its labor impact and the associated investment costs of achieving a desired energy mix. Another potentially interesting case that users may wish to consider is to construct time-varying job multipliers, if technological change is anticipated to make emerging technologies increasingly or decreasingly job-intensive over time.

References

Blyth, W., R. Gross, J. Speirs *et al.*, "Low carbon jobs: The evidence for net job creation from policy support for energy efficiency and renewable energy," UKERC 2014. https://ukerc.ac.uk/publications/low-carbon-jobs-the-evidence-for-net-job-creation-from-policy-support-for-energy-efficiency-and-renewable-energy/

E2-ACORE-CELI, 2020, "Clean Jobs, Better Jobs: An examination of clean energy job wages and benefits," https://e2.org/wp-content/uploads/2020/10/Clean-Jobs-Better-Jobs.-October-2020.-E2-ACORE-CELI.pdf

IMF, 2020, "Mitigating Climate Change – Growth- and Distribution-Friendly Strategies," Chapter 3, WEO October 2020, Washington D.C.

IMF, 2021, "Reaching Net Zero Emissions," G-20 Note, June 2021, Washington D.C.

IEA, 2020, "Sustainable Recovery," World Energy Outlook special report in collaboration with the IMF

IRENA, 2019, "Renewable Energy and Jobs Annual Review 2019," Abu Dhabi, U.A.E. https://www.irena.org/publications/2019/Jun/Renewable-Energy-and-Jobs-Annual-Review-2019

Mohommad, A., 2021, "Employment Effects of Environmental Policies—Evidence from Firm-Level Data," IMF Working Paper 2021/140, Washington D.C.

Pehl, M., A. Arvesen, F. Humpenöder *et al.* "Understanding future emissions from low-carbon power systems by integration of life-cycle assessment and integrated energy modelling," *Nat Energy* 2. https://doi.org/10.1038/s41560-017-0032-9

Power For All, 2019, "Powering Jobs Census 2019: The Energy Access Workforce," https://www.powerforall.org/resources/reports/powering-jobs-census-2019-energy-access-workforce

Wei, M., S. Patadia, and D. Kammen, 2010, "Putting renewables and energy efficiency to work: How many jobs can the clean energy industry generate in the US?," Energy Policy 38. https://doi.org/10.1016/j.enpol.2009.10.044

Annex

To illustrate the computation of the job-years per GWH multiplier, consider a utility that produces 100 MW at peak generation. Let us further assume that it has a load factor of 85%, a life span of 40 years. The utility generates 4 CIM jobs per year per MW (or 4 person-years of jobs per MW), and 2 O&M jobs per year per MW over the lifetime of the utility. Table 4 shows the conversion of this information to jobs per GWH of installed capacity.

(i) As the CIM jobs are front-loaded, these are levelized, or expressed as an average over the lifetime of the utility.

(ii) As utilities' peak generation is typically less than 100% of rated capacity (i.e. the load-factor is less than 1), the peak generation is grossed up by the load factor to reflect the higher installed capacity. If information on CIM and O&M jobs per MW of capacity is available, the grossing-up step is not required.

(iii) To express these multipliers from MW to GWH, we divide by 8760 (hours per year) x 1000 (1GW = 1000MW). Finally, the sum of the CIM and O&M figure yields the direct multiplier in job-years per GWH. The total multiplier is the product of direct and estimated indirect multiplier. In the template, the indirect multiplier is assumed to by 90% of the direct multiplier, following WPK (2010).

Table A1: Calculating jobs per gigawatt-hour

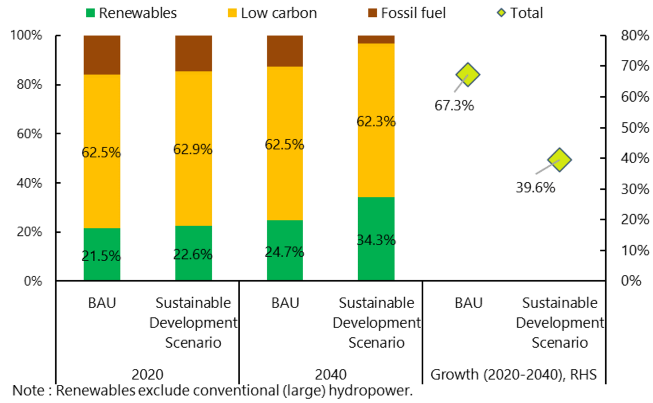
A	Peak output (MW)	100
B	Life span (years)	40
C	Load factor	0.85
D	CIM jobs/MW (peak)	4
E	O&M jobs/year/MW (peak)	2
	Lifetime average per MW (peak)	
F=D/B	CIM	0.10
G	O&M	2.00
	Lifetime average per MW (installed)	
H=F/C	CIM	0.12
I=G/C	O&M	2.35
	Job elasticity per Gigawatt hour	
J	CIM (=H / 8760 x 1000)	0.01
K	O&M (=I / 8760 x 1000)	0.27
J+K	**Total direct elasticity**	**0.28**

Figures for An Application to Brazil

Figure A1: Generation growth and shares of types

Brazil: Generation shares % of total

(percent)



Note : Renewables exclude conventional (large) hydropower.

Figure A2: Generation growth by source

Brazil: Generation growth (annual avg. 2020-40)

(Percent)

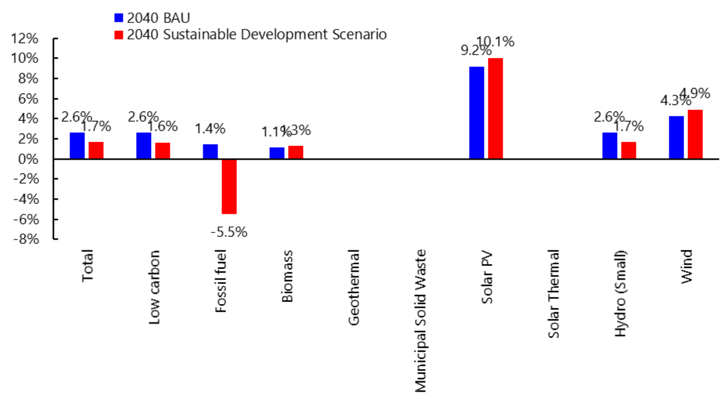
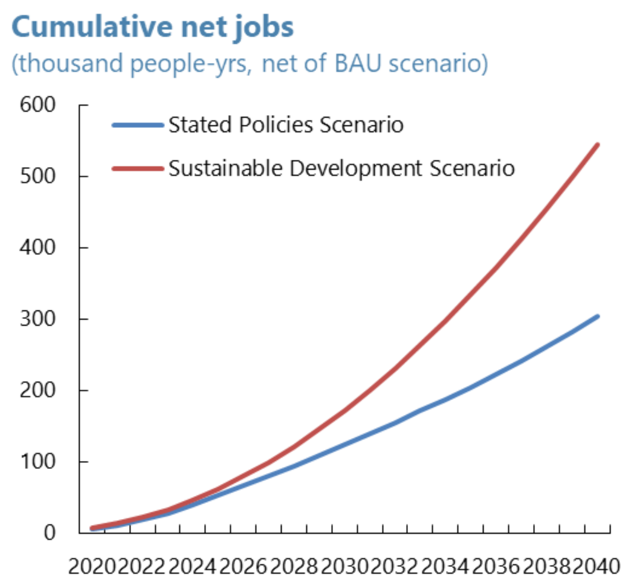


Figure A3: Net Cumulative jobs



Note : SPS (Stated Policies Scenario), SDS (Sustainable Development Scenario), BAU (Busines as usual)

Figure A4: Net jobs by source (annual flow)

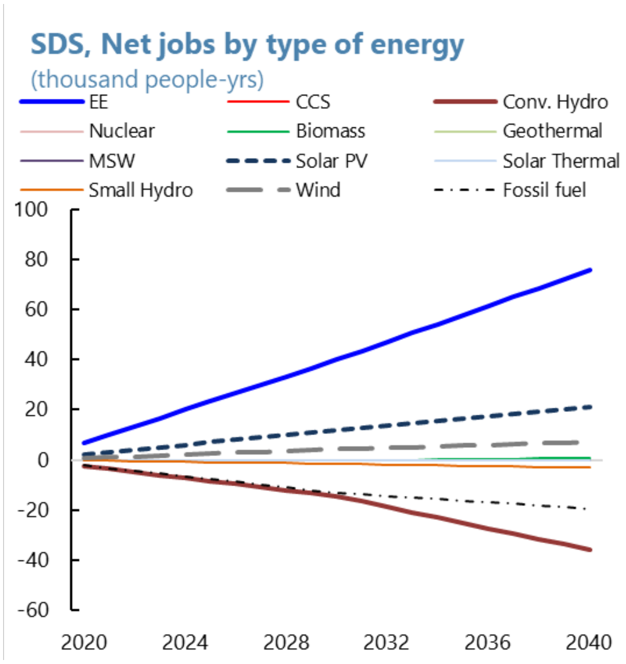
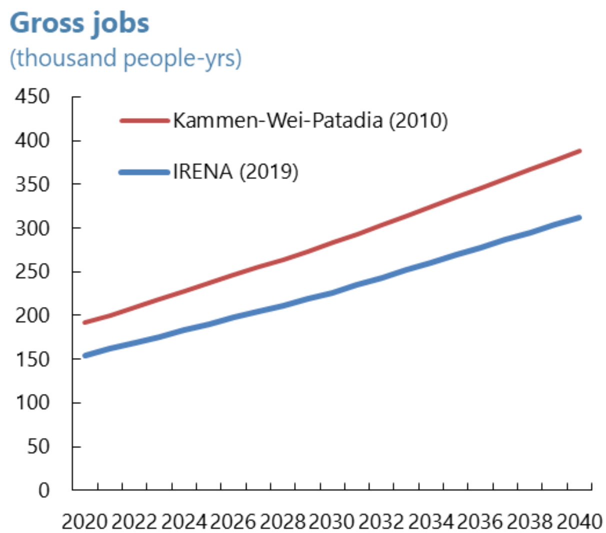


Figure A5: SDS gross jobs (alternative multipliers)



Note: KWP = Kammen, Wei, Patadia (2010)

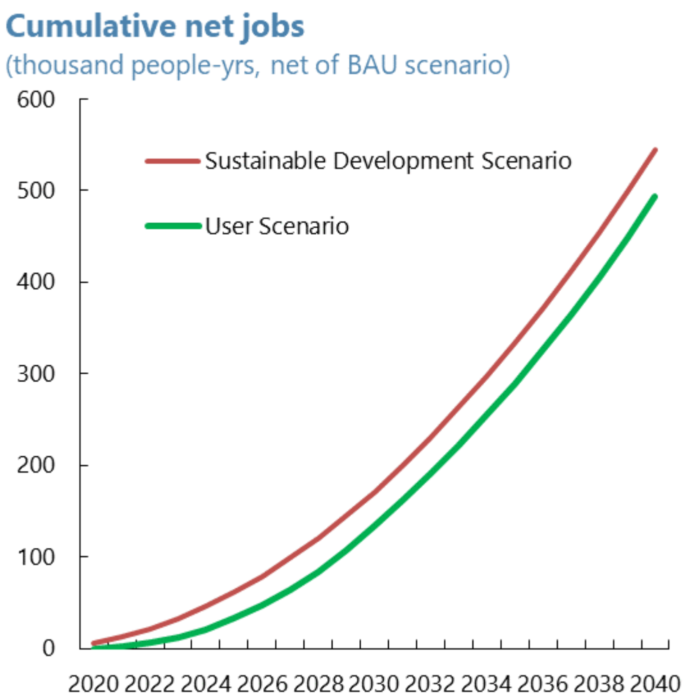
Table A2: Brazil USER scenario assumptions

Brazil: Comparative scenario assumptions

	BAU	SDS	USER
GENERATION ASSUMPTIONS	2040	2040	2040
Electricity (GWH)	1053000	854000	1006933
Total increase since 2020	67.3%	39.6%	60.0%
EE Savings	...	18.9%	4.4%
RENEWABLE SHARES	**25%**	**34%**	**41%**
Biomass	6.7%	8.5%	18.9%
Geothermal	0.0%	0.0%	0.2%
Solar PV	2.8%	5.0%	4.0%
Solar Thermal	0.3%	0.4%	0.2%
Hydro (Small)	3.0%	3.0%	6.0%
Wind	12.0%	17.3%	12.0%
LOW CARBON SHARES	**62.5%**	**62.3%**	**52.2%**
Conventional Hydropower	58.1%	56.8%	42.0%
Nuclear	4.5%	5.5%	10.1%
HIGH CARBON SHARES	**12.7%**	**3.4%**	**6.6%**
Petroleum	1.1%	0.0%	0.1%
Other	0.1%	0.1%	0.0%
Coal	1.9%	0.0%	2.5%
Natural Gas	9.6%	3.3%	4.0%
Total	100%	100%	100%

Note: BAU=business as usual, SDS=sustainable development scenario, User=user-specified scenario.

Figure A6: Brazil USER scenario cumulative net jobs



Note : Sustainable Development Scenario and User Scenario are derived from assumptions as shown in Table A2. BAU = Business as Usual.

Data sources.

Data for the IEA's BAU, SPS and SDS scenarios for the US, Brazil, China, India, Japan, Russia, and South Africa are taken from IEA's 2019 World Energy Outlook.

Data for renewable energy jobs and renewable energy generation capacity used to calculate the job multipliers in Table 2 in the text are taken from IRENA "Renewable Energy and Jobs Annual Review (2019), and IRENA renewable energy generation statistics: https://www.irena.org/Statistics/Download-Data.

Firm-level data on employment ratios are from Worldscope. The Worldscope sample covers 42,000 firms globally. Of these, there are more than 2200 firms directly in operation in energy-related sectors, including fossil fuel industries, nuclear and renewable manufacturing and services, and electric utilities. In addition, it includes firms that are likely to be indirectly engaged in manufacturing (e.g. of machinery and equipment) and service activity (e.g. transportation and construction) linked to the energy sector. However these linkages between energy sector firms and other firms cannot be inferred from the dataset.

PUBLICATIONS

Jobs Impact of Green Energy
Working Paper No. **WP/2022/101**