The Impacts of Skills Shortages on Global Power Sector Emissions

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This study, conducted by NewClimate Institute, explores the relationship between shortages of workers for the energy transition and global emissions pathways. Using a novel, theoretical model which links labour supply and renewable energy development, potential impacts of labour shortages on global emissions are demonstrated. To further assess countries' current readiness to mobilise the workforce needed for the energy transition, the study assesses empirical evidence for barriers slowing workforce expansion in renewable energy sectors and presents the Labour Market Transition Potential Index. This index combines indicators across labour market, demographic and institutional dimensions to provide a snapshot of countries' current potential to supply skilled workers to the energy sector. The results highlight the complexity of the challenge and importance of forward planning to ensure sufficient skills are in place to facilitate the energy transition.

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Authors

Lotta Hambrecht, Mats Marquardt, Rory Geary

Disclaimer

The authors have attempted to provide up-to-date and reliable information to the maximum extent possible in this report, however, they cannot be held legally responsible for its absolute accuracy. The information presented was provided at the time of research and may change over time. The results presented here may not necessarily represent the opinion of the donor and GIZ.

Abbreviations

APS	IEA World Energy Outlook Announced Pledges Scenario
BMZ	Germany's Federal Ministry for Economic Cooperation and Development
CCUS	Carbon Capture Utilisation and Storage
CPD4E	Career Path Development for Employment project
GDP	Gross Domestic Product
GIZ	Deutsche Gesellschaft für Internationale Zusammenarbeit
IEA	International Energy Agency
ILO	International Labour Organisation
IRENA	International Renewable Energy Agency
PAM	Partnerships for Development-Oriented Vocational Training and Labour Migration
STEM	Science, Technology, Engineering and Mathematics
STEPS	IEA World Energy Outlook Stated Policies Scenario
TVET	Technical and vocational education and training
UNESCO	United Nations Educational, Scientific and Cultural Organization
WEO	The IEA's World Energy Outlook

Executive Summary

Accelerating the global energy transition requires a rapid and large-scale expansion of the renewable energy workforce. To meet the goal of tripling global renewable power capacity by 2030, it is estimated that the number of workers in the power generation sector must grow from around 12.5 million in 2021 to 47 million in 2030 (see Figure 1, Panel A)[1]. Most of this demand is concentrated in manufacturing, installation and the operation and maintenance of renewable energy systems.

Shortages of workers and skills present major risks to achieving global climate targets. This study explores potential consequences for emission trajectories from failing to dedicate the necessary resources to investing in skills and workers. **Labour shortages can quickly compound, pushing renewable energy development off-track and jeopardising global efforts to limit climate change.**

If only 20 to 60% of new labour demand would be met annually across technologies and regions, **the world could face a shortfall of up to 6 million workers by 2030[2].** If these labour shortages cause equivalent delays in building new renewable generation capacity, progress in energy decarbonisation could be derailed, even if other political and economic barriers are successfully overcome.

By 2030, global renewable generation capacity could fall nearly 10% short of the pledged tripling target (see Figure 1, Panel B). This would extend the life of fossil fuel generation around the world, driving power sector emissions 12 percent above the 2030 targets pledged by governments, and more than doubling them by 2045 (see Figure 1, Panel C). As a result, this would push the global power sector off a 1.7°C warming pathway and closer to 2.4°C, well beyond the 1.5°C limit set by the Paris Agreement.[3]

[1]Renewable energy trajectories from the IEA World Energy Outlook's (WEO) Announced Pledges Scenario (APS), which reflects current government decarbonisation pledges (IEA, 2024), and employment factors from Rutovitz et al. (2015) and Ram et al. (2022) are used to estimate direct workforce needs for installed power capacity and generation.

Labour supply and electricity capacity projections are a theoretical and exploratory modelling exercise representing selected possible pathways. These scenarios should not be interpreted as precise forecasts of expected labour shortages or their outcomes. The modelling is intended to highlight the cascading effects and systemic interlinkages that skill gaps can trigger at the global level. Estimates are intended to underscore the importance of proactive planning, helping to address what could otherwise become a critical bottleneck in the global energy transition.

[2]This figure does not include the additional labour needed to expand power grids and support related supply chains.
[3]Temperature pathways are based on WEO's APS (1.7°C) and STEPS (2.4°C) scenarios.

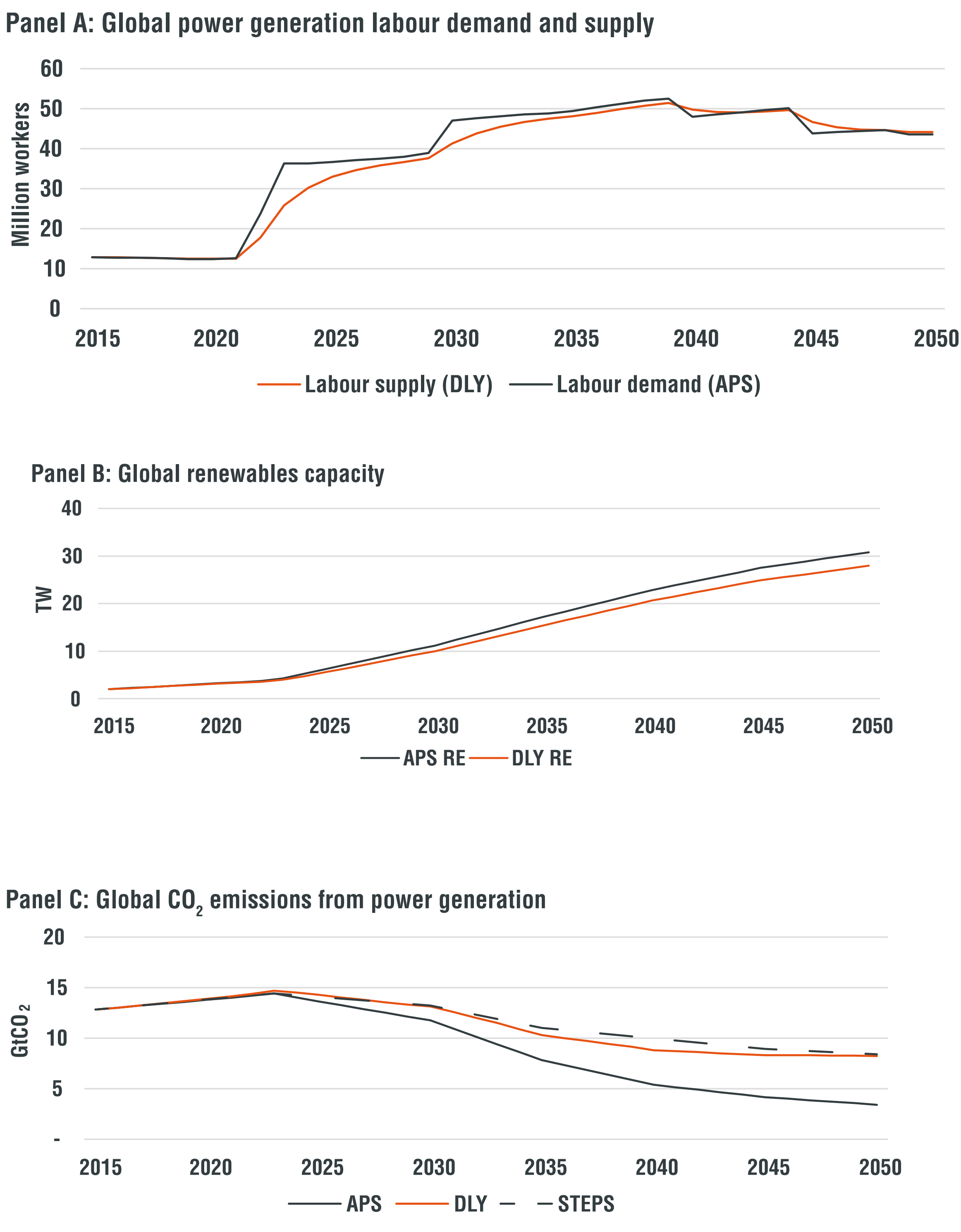

Figure 1: Global power generation labour demand and supply, renewables generation capacity, and global power generation CO2 emissions modelled by the authors based on IEA's World Energy Outlook (WEO) (2024). Panel A shows Labour demand (APS) based on the WEO's Announced Pledges Scenario, and Labour supply (DLY) as a stylised delayed labour market response. Panel B compares global renewable capacity deployment under the WEO's APS (APS RE) and delayed renewable capacity development due to labour shortages (DLY RE). Panel C shows power sector emissions based on the WEO's APS, under modelled labour shortages (DLY), and based on the WEO's Stated Policies Scenario (STEPS) (shown for reference).

Countries face complex and multidimensional challenges in building the workforce needed for the energy transition. These challenges vary widely depending on national circumstances and include:

- **Labour market and demographic constraints** such as ageing populations, low labour force participation rates and limited inward migration reduce the available pool of workers and restrict labour force flexibility.

- **Education and training systems not keeping pace** with the rapid growth in demand for skilled workers, both in terms of the number of available spots for students, as well as the labour market relevance of their curricula. This is particularly pronounced in developing countries where educational infrastructure and funding remain limited.

- **Slow transitions from fossil fuel to renewable energy sectors.** Despite overlapping skill sets, worker transitions remain limited. Reasons include mismatches in the location and timing of the phasing-out of fossil jobs versus job creation in renewables, insufficient retraining support, and differing job characteristics.

Countries can draw on three main groups to expand their energy transition workforce: recent domestic graduates, skilled migrants, and workers transitioning from related sectors in the domestic economy.

The required pace of workforce expansion differs by region, with particularly rapid growth estimated in Asia and South America. Yet, countries differ significantly in their potential to mobilise the workforce needed for the energy transition. To explore these differences, the Labour Market Transition Potential Index was developed (see Figure 2). Drawing on existing empirical research, the index consolidates a range of indicators spanning the education levels of the population, STEM and vocational education statistics, net migration, age of the population and wage premiums available in energy transition sectors.[4]

[4] For a full description of the index and how it is constructed please refer to Section 3 and the Technical Annex in the full report.

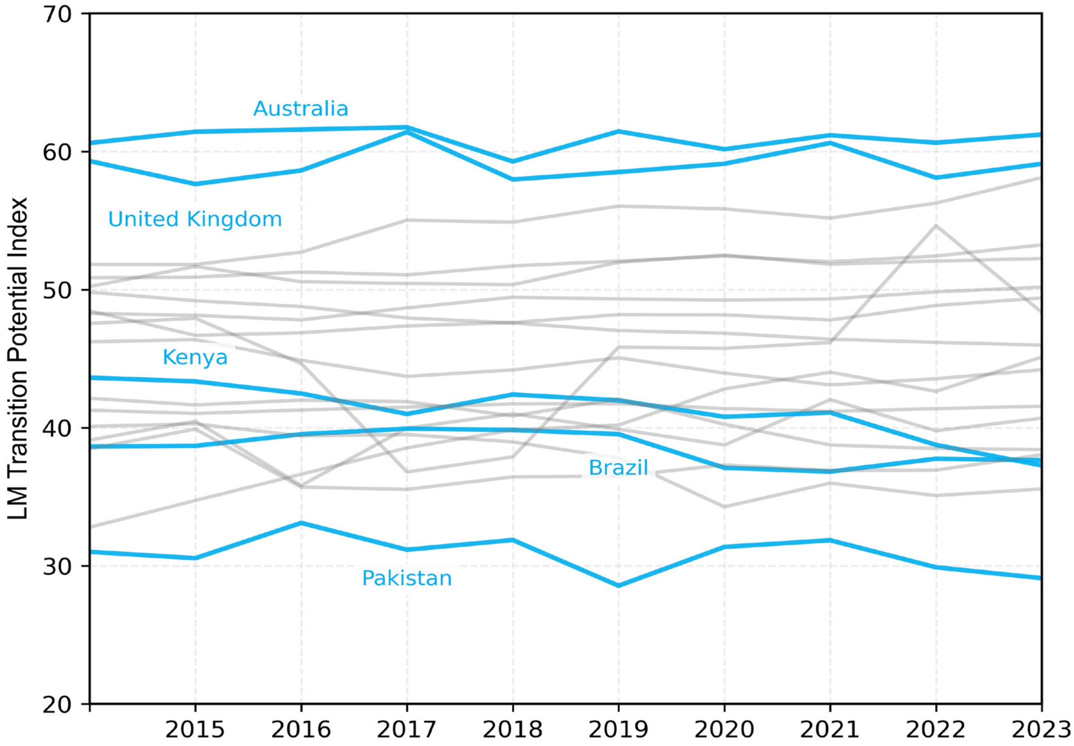

Figure 2: Labour Market Transition Potential Index. Higher scores indicate a higher theoretical potential to supply workers to energy transition sectors.

High-income nations tend to score well on education and institutional capacity but also contend with older populations and greater competition for workers from other economic sectors. The results suggest that making energy transition jobs more attractive, such as through better wages, working conditions, and career prospects, should be a key priority for both governments and companies. Developing programmes to bring marginalised groups into the workforce can also be explored in high-income countries.

In contrast, **emerging economies generally benefit from younger populations and stronger wage incentives in the energy transition sectors. Yet they face significant challenges, such as lower levels of education within the labour force and the outflow of skilled workers.** Our modelling estimates that, by 2030 shortages of workers with technical, vocational or university-level qualifications could be 35% higher than today. Meeting this rising demand will require substantial investment in training systems and institutional capacity to upskill workers at scale. While high-income countries appear to already be drawing on migration as a source of workers for renewable energy development, shortages of workers are a global issue. An effective and fair response necessitates international cooperation. Absent the necessary commitment to investing in skills and a collaborative approach across countries, climate goals will remain out of reach.

Contents

1 The Climate Impact of Green Skills Shortages

Employment in renewable energy sectors is growing very rapidly as installation ramps up around the world. Direct and indirect employment in solar, wind, hydro and bioenergy grew by an impressive 33% between 2022 and 2023 (IRENA and ILO, 2024).

Labour shortages in the power sector now present a significant risk to the necessary pace of renewable energy deployment required for the global transition. While the downward march of renewable energy technology costs continues (Wood Mackenzie, 2024), many countries are already experiencing shortages of skilled labour in key occupations within the power sector (IRENA and ILO, 2024; IEA, 2025). A survey by the International Energy Agency (IEA) (2025) of energy employers across Europe, the Americas, Africa and Asia Pacific found widespread difficulties in recruiting qualified applicants across nearly all occupational categories.

Countries have pledged to triple renewable power capacity by 2030 to help keep the Paris Agreement target of limiting global warming to 1.5°C within reach (COP28 et al., 2023). Achieving this goal will require rapid growth in the global power generation workforce, with employment projected to rise from 12 million in 2020 to 47 million by 2030 (see Labour demand (APS) in Figure 3). The largest labour demand will be in manufacturing, construction, and installation of renewable energy technologies, with the Asian region requiring the most workers due to rapidly growing energy demand. In addition to these direct employment needs, substantial numbers of workers will be needed in related sectors such as grid expansion. Labour shortages could therefore become a critical bottleneck, adding to technological and financial barriers, and threatening both government pledges and the Paris Agreement temperature goal. To illustrate these cascading risks, we present an exploratory model linking labour shortages to global temperature outcomes.

Our analysis indicates that by 2030, the renewable power generation sector could face a shortfall of up to 6 million workers, assuming that labour supply only can close between 20-60% of additional labour demand annually across technologies and regions. While the rate in which labour markets can adjust to increasing demand for workers in renewable sectors is difficult to model, specifically on the global level, evidence suggests that green skill demand is rising far faster than the labour market can keep up (LinkedIn, 2024). Figure 3 illustrates, on an aggregated and simplified basis, that labour supply, (Labour supply (DLY) in the chart), may significantly trail behind labour demand (Labour demand (APS))[5] . This labour supply shortage is particularly pronounced during periods in which the APS foresees accelerated renewable capacity expansion, such as the years leading up to 2023 and 2030. As growth slows around 2040, labour supply may gradually converge with or even exceed demand. While not explicitly modelled here, and inherently uncertain, trends in automation could further attenuate labour demand in the longer term.

[5]Please refer to Section 5 Technical Annex for a detailed discussion of the methodology underlying the modelling exercise.

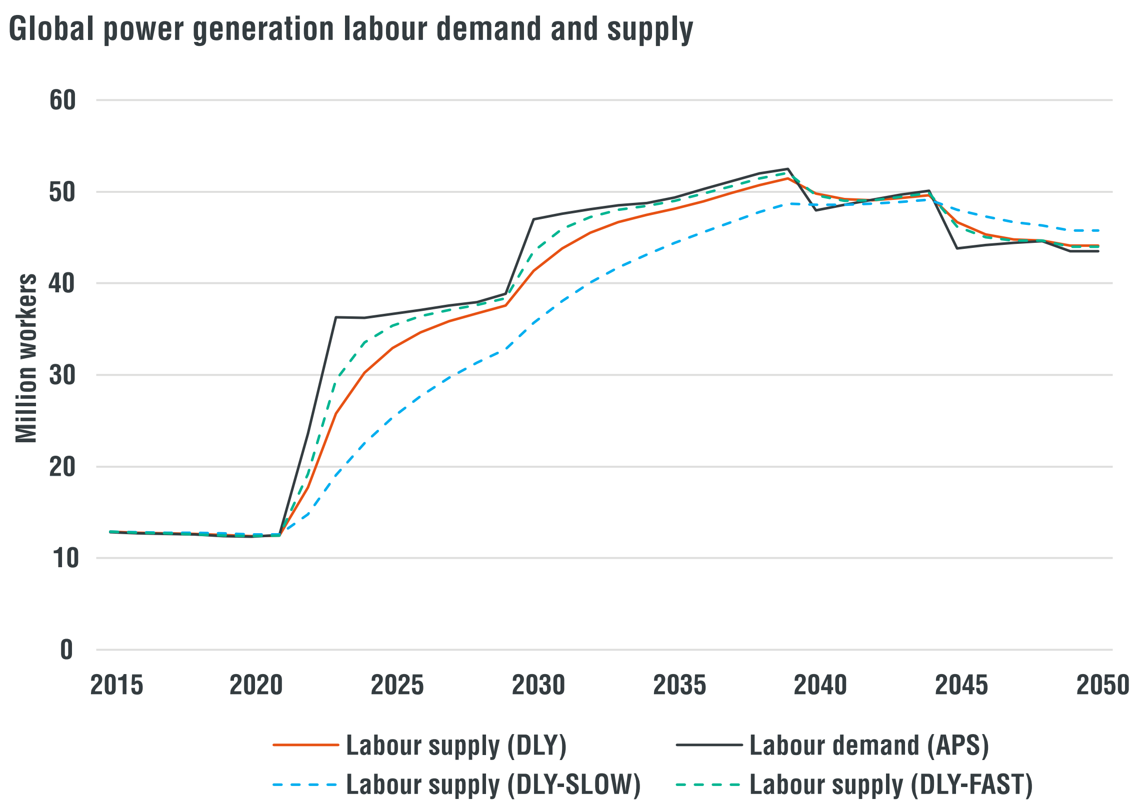

Figure 3: Global labour demand and supply for power generation capacity. Labour demand (APS) is based on the WEO's Announced Pledges Scenario, while Labour supply (DLY) represents a stylised labour market response. DLY-SLOW and DLY-FAST illustrate scenarios where labour market adjustments occur much slower and faster, respectively. While not statistical confidence intervals, these bounds reflect a range we consider likely to capture realistic scenarios.

Labour shortages are likely to be most severe in the Manufacturing and Construction & Installation phases of solar PV and battery storage, particularly in Southeast Asia, Africa, and the Asia Pacific region (see Figure 4, Panel A-C). This reflects both the rapid pace of capacity expansion required in these regions and technologies, and region-specific differences in labour market readiness (see Section 5 for how our modelling tries to account for these factors, and see Section 3 for further detail on different regions' labour market readiness).

[6]Our estimates of labour demand and supply are based on employment factors from Rutovitz et al. (2015) and regional adjustment factors from Ram et al. (2022). As they are slightly outdated, they are likely to overestimate labour force needs, specifically in those value chain segments that have benefited hugely from automation in the last decade, e.g. manufacturing.

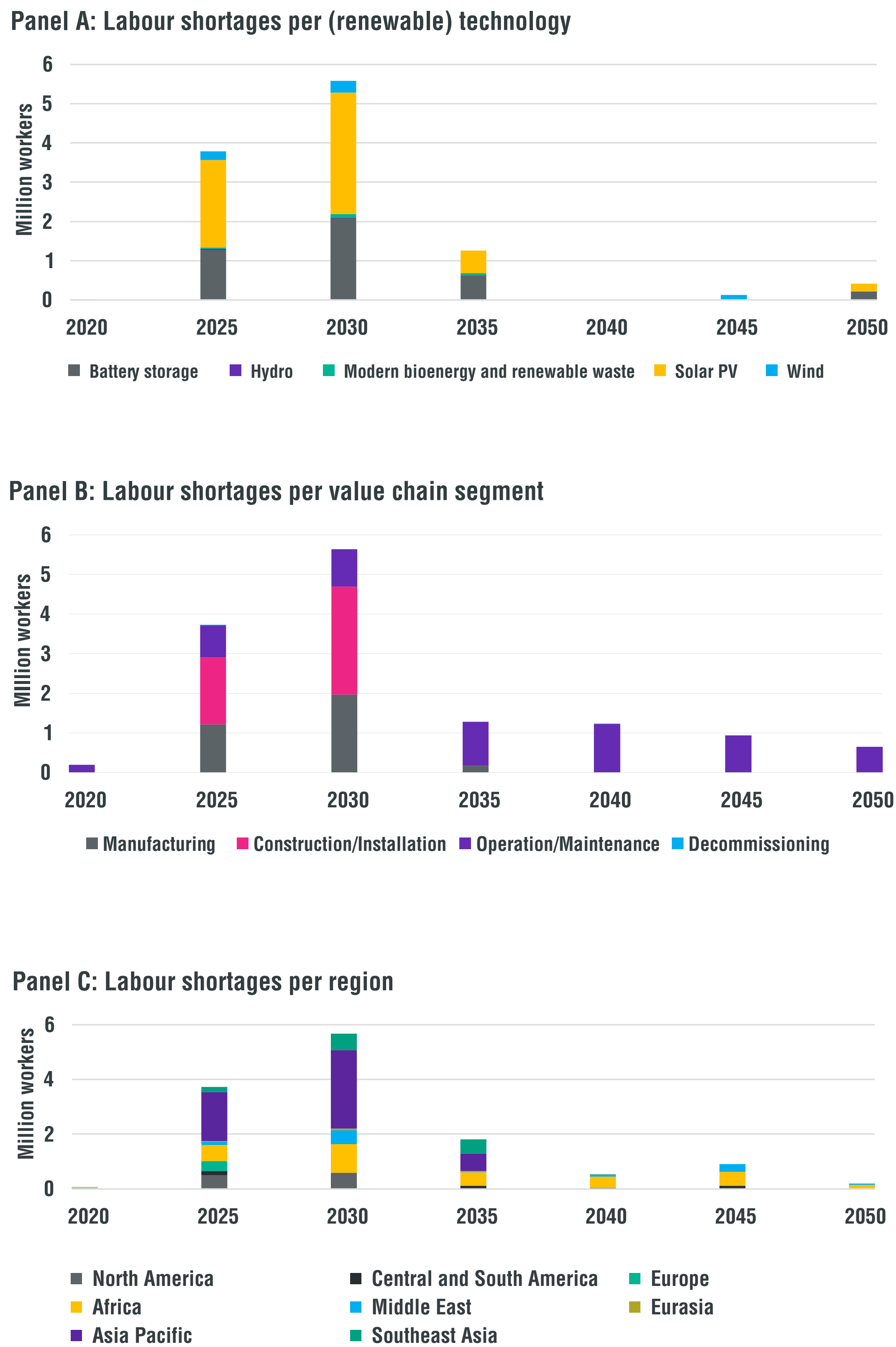

Figure 4: Labour shortages broken down by technology, value chain segment, and region.

The shortage of workers can also be translated into the missing educational qualifications that would be required to fill demand for skilled and unskilled power sector positions. These reflect the occupational profiles associated with different technologies and different segments of their value chains. Using wind and solar as examples, the desired minimum level of education by employers for their respective occupations is found to differ over time (see Figure 5Figure 5). In the short-term, labour shortages are concentrated in roles requiring lower- to mid-level education. By 2030, about 20% of the labour shortage may rely on workers who have a high school or lower level of education at minimum, 60% on workers who have an apprentice-level or post-secondary credential, and 20% on workers who have a bachelor's or postgraduate degree. This represents significant growth from today - the shortage in workers with apprentice-level education or post-secondary credentials, plus workers with bachelor's or postgraduate degrees, would be about 35% higher by 2030.

Over the longer term, however, labour demand is likely to shift toward more highly educated workers, as the initial need for lower-skilled construction and installation roles declines and operations and maintenance roles make up a larger share of total employment. By 2050, the share of the labour shortage that relies on workers with a high school or lower level of education may fall to 15%, while those with bachelor's or postgraduate degrees rises to 30%. Closing the gap will require early investments in education and training systems as aligning curricula with evolving labour market needs, training educators and having students complete their qualifications takes significant time.

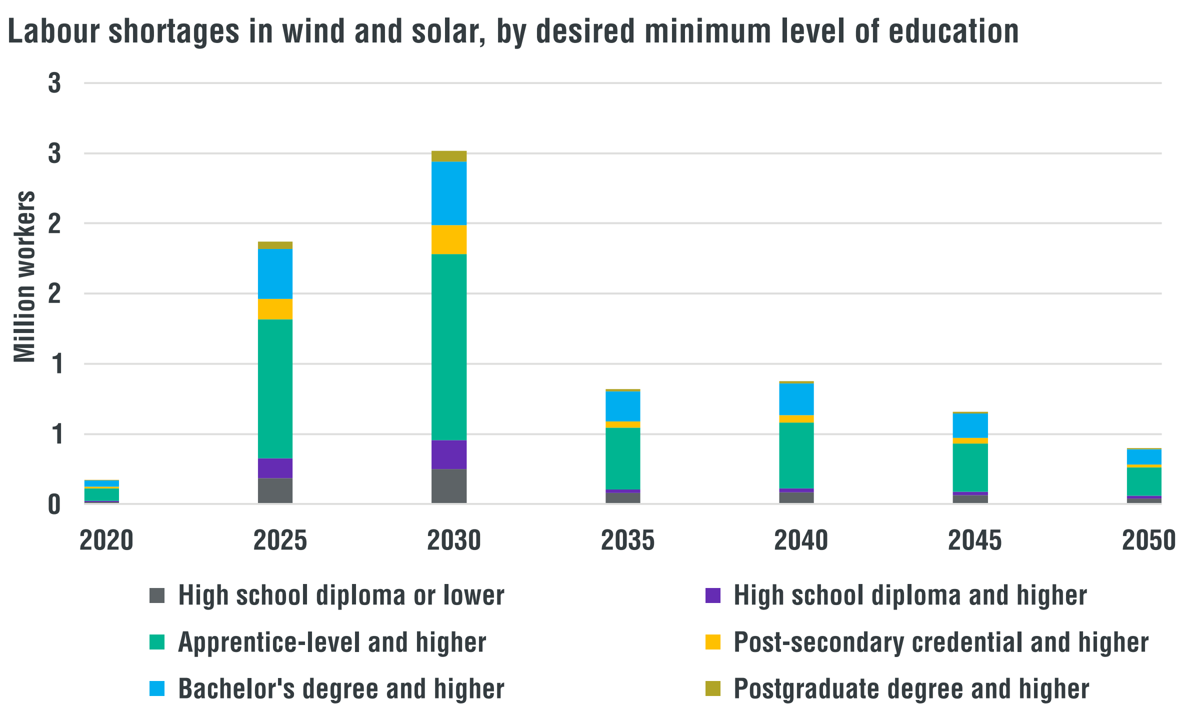

Figure 5: Educational requirements for labour shortages in wind and solar PV (across Construction & Installation and Operations & Maintenance).

Labour shortages can become a significant bottleneck for the energy transition, with the potential to derail progress on the global power sector transition.

Global renewable power generation capacity in the DLY scenario could fall nearly 10% short of the pledged tripling target by 2030, as represented by the APS scenario (see Figure 6).

This estimate assumes that shortages, particularly in the critical value chain segments of Manufacturing and Construction & Installation, have an approximately proportional impact on delaying capacity development (see Section 5 for a methodological overview). In reality, the impact may be more or less pronounced, depending on factors such as the severity of labour shortages in specific segments, and the flexibility of the labour market to mitigate these constraints through measures such as overtime, automation, or reallocation of workers.

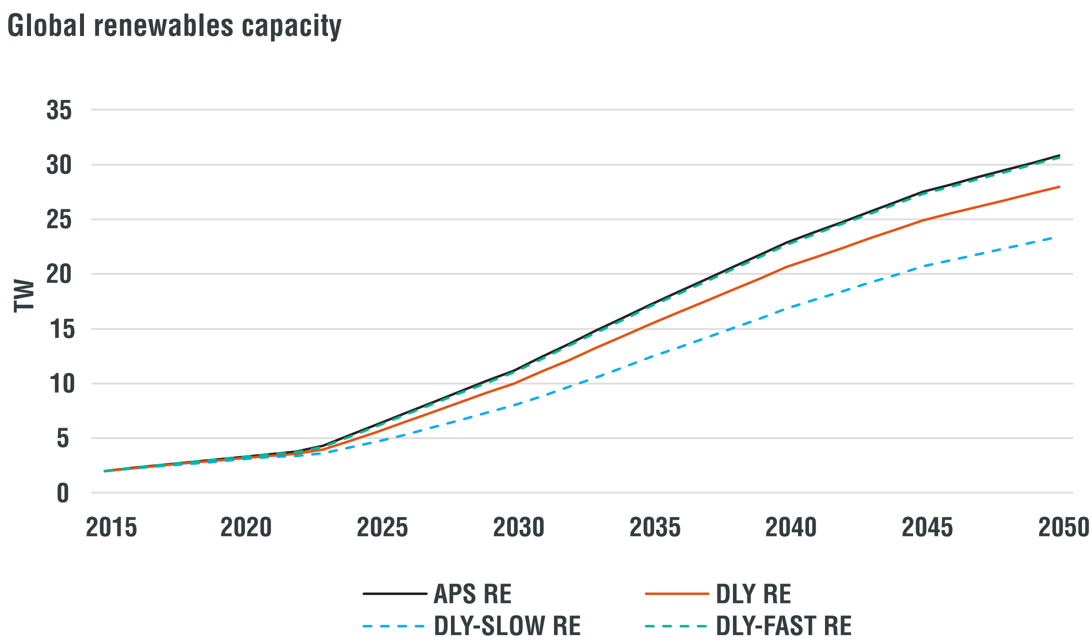

Figure 6: Global renewable power generation capacity under the WEO's APS (APS RE), compared to delayed capacity due to labour shortages (DLY RE). DLY-SLOW RE and DLY-FAST RE show alternative scenarios, reflecting slower and faster labour adjustments, respectively, and varying levels of impact from modelled labour shortages on capacity development.

As the expansion of renewable power generation capacity falls short of government pledges, meeting global power demand increasingly depends on delaying the phase-out or phase-down of fossil-based generation. As a result, the global share of renewables-based power fails to reach the levels committed to by governments (see Figure 7). With simplified assumptions on how shortfalls in renewable capacity are compensated for, we model an extended reliance on fossil fuels across all regions (see Section 5 for methodology). In North America, for instance, governments plan to phase out unabated coal in the power sector by 2035 under the APS scenario. Yet, due to labour shortages in renewable deployment, coal may remain in use until 2050. In Southeast Asia, the phase-down of unabated coal and fossil gas is also likely to proceed more slowly in the DLY scenario than pledged.

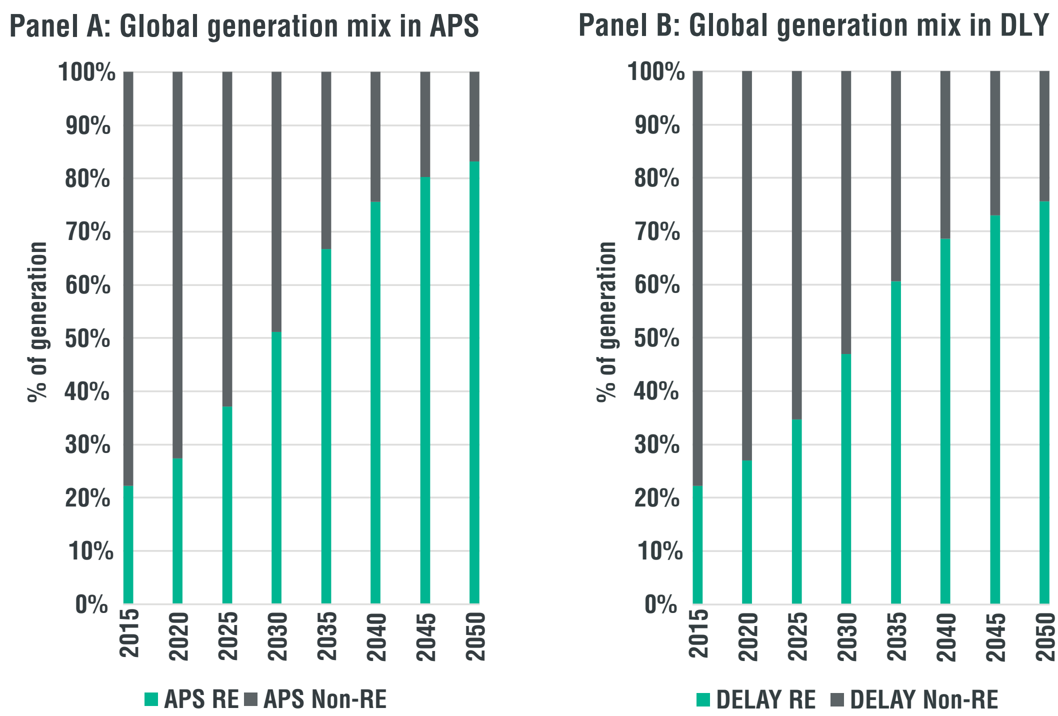

Figure 7: Global power generation mix in WEO's APS compared to generation mix in DLY scenario impacted by modelled labour shortages.

As labour shortages in the renewables-based power sector lead to prolonged fossil fuel use, this results in higher carbon emissions over an extended period. Our estimates suggest that power sector emissions could be 12 percent above pledged levels by 2030 under the APS scenario, and more than double by 2045 in the DLY scenario (see Figure 8). While the APS scenario would place the global power sector on a 1.7°C warming pathway (IEA, 2024), labour constraints could shift the trajectory closer to the IEA's STEPS scenario, which is associated with a 2.4°C pathway. This would move the sector significantly off course from the Paris Agreement's 1.5°C goal.

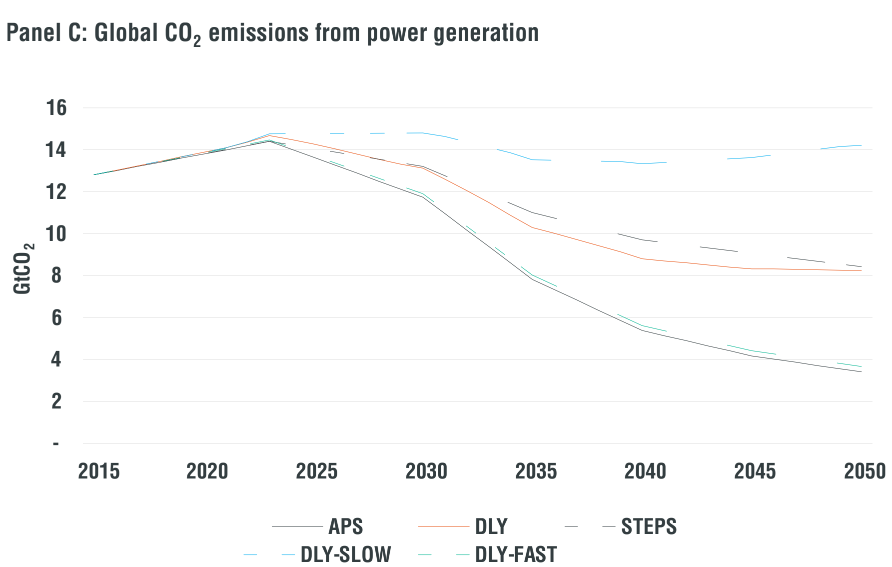

Figure 8: Global CO2 emissions from power generation based WEO's APS and STEPS scenarios, compared to emissions in DLY scenario impacted through modelled labour shortages. DLY-SLOW and DLY-FAST provide and upper and lower bound for theoretically feasible scenarios, based on the range of labour force and capacity development adjustment coefficients used in this study (see Section 5 for details).

It is important to emphasise that this is a theoretical and exploratory modelling exercise. The illustrative pathways presented here reflect just one possible scenario among many, and the range of potential outcomes expands rapidly with each additional layer of assumptions.

This is evident in the widening gap between the DLY-SLOW and DLY-FAST scenarios, particularly as the analysis progresses from labour shortage estimates to emissions pathway projections.

These scenarios should not be interpreted as precise forecasts of expected labour shortages or their outcomes. Rather, the value of this modelling lies in its ability to highlight the cascading effects and systemic interlinkages that skill gaps can trigger at the global level. Our estimates are therefore intended to underscore the importance of proactive planning, helping to address what could otherwise become a critical bottleneck in the global energy transition.

In the next sections we explore the empirical evidence seeking to explain the reasons behind workers shortages in energy transition sectors.

2 Barriers to Building a Green Workforce

Skilled labour shortages are not unique to the power sector and reflect broader structural factors at play in many regions of the world. Many countries now face economy-wide worker shortages for various reasons, reflected, for instance, by a low labour force participation rate, high old-age dependency ratio or low migration inflows (Groiss, 2023; Feist, 2024). In these cases, labour demand can outpace labour supply over time.

The complexity of the skills in demand can also contribute to shortages. Shortages tend to be greater for innovative activities that require highly skilled workers, such as activities involving green technologies, digitalisation, and artificial intelligence (Marcolin and Filippucci, 2025). A high degree of competition for skilled workers between adjacent or interconnected supply chains (as is common in the automative industry, for example) can also lead to labour shortages (Briggs et al., 2022) as well as education and training systems not keeping pace with innovative technologies and new market demands (ILO, 2019).

To address skilled labour shortages for the energy transition, countries can draw from three main groups of potential workers: new labour market entrants, workers from fossil fuel sectors or related technical fields, and migrant workers. However, there are barriers that can prevent potential workers from matching with new jobs.

Labour Market Entrants

Recent graduates with relevant education and training, who have not yet committed to other sectors of the economy, will be the best available source of skilled labour. However, universities and vocational schools are struggling to keep up with the rapid, near-term growth anticipated for highly skilled workers[7] (ILO, 2019), both in terms of the number of available spots for students, as well as the labour market relevance of taught knowledge and skills. On a global scale, most energy-related degrees still focus on fossil fuels, providing graduates with insufficient skills and knowledge (Vakulchuk and Overland, 2024). Over the last decade many universities have added courses on renewable energy technologies to their traditional science and engineering programmes, but specialised programmes targeted at the renewable energy sector are still lacking in many countries, particularly in developing countries (Vakulchuk and Overland, 2024).

[7] Following definitions by the International Labour Organization (2025), under International Standard Classification of Education 2013, skilled workers are understood as medium-skilled workers (having upper secondary level of education or post-secondary, non-tertiary education) and highly skilled workers (having short-cycle tertiary education or Bachelor's, Master's or Doctoral or equivalent level), which provide a basis for entering jobs in renewable industries.

Targeted vocational programmes for renewable energy technologies are also not expanding fast enough to keep up with anticipated skills demand. The misalignment of current education and training offers with labour market needs is particularly pronounced in developing countries, mainly due to underfunding, and a lack of skilled educators, infrastructure and curricula (Vakulchuk and Overland, 2024), as well as limited involvement of the private sector in the development and delivery of technical and vocational education and training (TVET). Improving the alignment of education and training offers with in-demand skills in green sectors can be achieved through multi-stakeholder initiatives, such as the Deutsche Gesellschaft für Internationale Zusammenarbeit's (GIZ) Future Professionals: Skills for the Green Economy in Brazil (see Box 1).

Box 1 **Brazil - Future Professionals: Skills for the Green Economy**

The Future Professionals: Skills for the Green Economy project, implemented by Brazil's Ministry of Education and GIZ on behalf of the German Federal Ministry for Economic Cooperation and Development (BMZ), is undertaking activities to improve the employment prospects of TVET graduates in strategic green economic sectors in Brazil.

GIZ advises Brazil's Ministry of Education, Ministry of Labour, National Service for Industrial Training and the Federal Network of TVET Institutes, as well as universities, companies and associations, on developing labour market-relevant, in-demand education and training for students for strategic green economic sectors (renewable energies, bioeconomy and circular economy). There is particular focus on improving TVET and employment opportunities for women and vulnerable groups in these sectors.

Activities in the first phase of the project, launched in 2021, included developing demand-oriented curricula and teacher training in conjunction with the private sector, assessing existing course offerings and employability of graduates, providing inputs for the modernisation of TVET guidelines and promoting partnerships between relevant ministries, educational institutions and companies – always with the focus on the promotion of a green economy. Targeted activities for women included, for example, awareness courses for educators, workshops in schools, and individual mentoring for young women starting or aspiring to work in the energy sector.

The project's success hinges largely on its multi-pronged approach, combining activities targeted at curricula, teachers, and students together with awareness-raising across all levels, from government to educational institutions and the private sector. In the first phase, 72 new or updated curricula were developed, 25 of which focus on renewable energy and energy efficiency, and 1,180 TVET teachers (over 20% women) were trained or retrained in line with the modernised curricula. Between 2021 and 2023, 18,708 qualified professionals completed training, with over 70% improving their employment situation by 2024. In addition, the national inter-institutional programme EnergIFE was established to introduce for the first time renewable energies and energy efficiency in the public TVET system. EnergIFE is a multi-actor coordination framework legally anchored in the system, allowing sustainability beyond the project's lifetime.

The second phase of the project, launched in May 2025, will focus on further embedding TVET in ecological and economic transition planning, expanding sustainability-focussed TVET course offerings in the country, and developing active labour market measures for recent graduates to promote their transition from school to work.

Workers from Fossil Fuel Sectors

Fossil fuel workers or workers in related technical fields are often viewed as a natural source of workers to transition into renewable power generation due to overlapping technical skills and knowledge.

Opportunities to move into renewable industries may be limited due to temporal, spatial and educational barriers and difficulties in foreseeing the necessary changes. The creation of renewable jobs may not occur at the same pace, nor in the same location as the loss of fossil fuel-based jobs. Lim et al. (2023) demonstrate that in the US, for example, there is little co-location between current workers in fossil fuel extraction and current sources of renewable energy production, nor projected future green job growth. Opportunities might also be shaped by the urban-rural divide, whereby workers located in urban areas are better able to access green employment opportunities due to the concentration of industries, access to education and training, and available social and economic infrastructure to support a growing workforce in urban centres (Briggs et al., 2022; Causa et al., 2024). Furthermore, despite evidence of some skill overlaps between fossil fuel and renewable energy occupations, workers may require additional time, effort and monetary investment to attain additional qualifications. Thus far, predominantly highly educated and skilled workers have captured new green employment opportunities in countries which have been studied (Bergant et al., 2022b; OECD, 2023a). Initiatives to boost local job opportunities, such as GIZ's Career Path Development for Employment in South Africa (see Box 2), alongside targeted support programmes to assist workers with the personal and financial costs of transition can mitigate some of these barriers.

Box 2 South Africa – Career Path Development for Employment• Skills for a Just Transition

The Career Path Development for Employment (CPD4E) project improves employment opportunities in South Africa within the context of the just energy transition. By combining innovative pilots with systemic reforms, it reduces barriers to accessing training and jobs and strengthens the "just" dimension of South Africa's transition – fostering inclusive and sustainable employment.

Implemented by GIZ on behalf of the German Federal Ministry for Economic Cooperation and Development and co-financed by the European Union and the Swiss State Secretariat for Economic Affairs, CPD4E works closely with South Africa's Department of Higher Education and Training and a range of other public and private partners. The project adopts a multi-pronged approach, which includes tackling both the supply and demand sides of the labour market, integrating active labour market policies and strengthening the policy environment to promote sustainable employment within South Africa's transition to a low-carbon economy.

The project's focus areas include strengthening the enabling environment by building institutional capacity, fostering coordination between key stakeholders, expanding vocational training programmes in line with labour market needs, and supporting entrepreneurship and Micro, Small and Medium Enterprises to stimulate job creation in low-carbon sectors. Additionally, the project facilitates career transitions for young people – particularly women – and creates reskilling and upskilling opportunities for workers at risk of job loss by the transformation.

Since its launch in 2022, a range of initiatives targeted at different stakeholders have been implemented. One key example is the MpumaBiz Growth and Support Initiative, which empowers entrepreneurs in Mpumalanga - a province where coal mining is a major source of economic activity and jobs - to develop diversified, sustainable business models. As of March 2025, the initiative has supported 450 entrepreneurs (318 of them women), with 111 receiving further training and mentoring to refine their growth strategies and generate long-term employment. It is anticipated that 300 jobs will be generated through business expansion, providing new opportunities outside of the coal sector.

Through its multi-dimensional approach, the project demonstrates how skills development, support for entrepreneurship, and labour market integration can be brought together to promote inclusive and sustainable employment. Looking ahead, the project will continue to strengthen national frameworks and scale up and institutionalize successful approaches within national systems to ensure lasting impact.

Migrant Workers

Migration can play a critical role in alleviating labour shortages, particularly in the short term by delivering already-skilled workers. In several high-income countries, such as the United Kingdom, Australia and Spain, migrant workers already make up a significant share of the renewable energy workforce (Jobs and Skills Australia, 2023; Observatorio de las Ocupaciones, 2023; Springford, 2025). For instance, in Australia, 26% of the renewable energy workforce in 2021 was foreign-born. The share was even higher in certain occupations, with over half of electrical engineers being foreign-born. However, relying on migration has additional considerations. In destination countries, placing a sole focus on migration as a source of workers may risk underinvesting in the sustainable development of the domestic labour force, including investments in education and training, job quality and wages (Hooper and Huang, 2024). For origin countries, a high outflow of skilled workers can benefit the economy through remittance flows and potentially stimulate individuals and governments to invest in skills which can in turn benefit the domestic labour market. Moreover, migration can help reduce unemployment in sectors that have an oversupply of workers in the origin country. However, migration also poses a risk of human capital flight or 'brain drain' – the emigration of highly educated and skilled workers to other countries. Net exporters of highly skilled workers tend to be middle-income countries (World Bank, 2018; United Nations Population Division, 2024), which now account for a large proportion of global emissions and need to retain a sufficient level of skilled workers to support their transitions to renewable energy. To ensure migration is mutually beneficial to origin and destination countries, governments can utilise innovative immigration models including skills development partnerships, circular migration pathways, and apprentice and student exchanges (Mason et al., 2022). GIZ's Partnerships for Development-Oriented Training and Labour Migration (see Box 3) is an example of a migration model which, through its collaborative approach between origin and destination countries, also works to improve the domestic education and training opportunities in countries of origin.

Box 3 Jordan – Partnerships for Development-Oriented Training and Labour Migration

The Partnerships for Development-Oriented Vocational Training and Labour Migration (PAM) project, implemented by GIZ on behalf of the German Federal Ministry for Economic Cooperation and Development (BMZ), is developing and piloting concrete partnership-based approaches for vocational training and labour migration. The project aims to promote innovative cooperation models between governments, civil societies, the private sector and business associations to make international migration and mobility safe, orderly, and regular, and to harness it for development.

PAM supports individuals interested in migration by providing linguistic, cultural, administrative and professional preparation for international employment opportunities. The project promotes sustainable partnership models between private sector stakeholders in Germany and public institutions in countries of origin to facilitate matching of project participants with employment opportunities at German companies.

PAM first ran from 2019-2024, with a follow-up project running from 2024-2027. As of August 2025, PAM is active in Ecuador, Jordan and Viet Nam, with each partnership focussed on different occupations including, for example, electricians, industrial mechanics, machine cutting operators and mechatronics engineers, among others. In Jordan, there is a particular focus on professions relating to the decarbonisation of industry and society, prevention of environmental damage and conservation of natural resources. Here, GIZ works together with the German Confederation of Skilled Crafts (Zentralverband des Deutschen Handwerks) as well as different skilled crafts organisations, and the Ministry of Labour in Jordan to inform, deliver and adapt the programme.

In 2024, the first group of apprentices migrated from Jordan to Germany. The apprentices encountered difficulties with finding accommodation in Germany, aligning expectations about their qualifications and employment, and managing social integration. With lessons learned from these experiences, the second group of apprentices from Jordan will migrate in 2025. Overall, the project aims to facilitate the migration of 400 skilled apprentices / workers in total across all partner countries over the full project period.

Across all countries, the partnership model aims to benefit all parties involved. For apprentices and workers, it facilitates regular migration pathways, access to qualification opportunities and international work experience (also improving their employability in their country of origin if they choose to return). Partner countries can benefit from improvements of the curricula and personnel of their national TVET system, the integration of international approaches into TVET institutions and linkages to the German private sector. German companies can address labour shortages and receive support for integrating international talent.

3 Comparing Countries' Readiness

Supplying workers for the energy transition is a multidimensional challenge. To understand the challenge in greater depth and explore countries' potential readiness to undergo a labour market transition in support of their energy transition, we construct the Labour Market Transition Potential Index from a set of underlying indicators.

Inclusion of indicators is informed by evidence on the determinants of skilled labour availability in a country and worker characteristics in green sectors, as discussed in the previous section. Indicators are also included if there is a strong theoretical argument for their inclusion.

We consider that the key dimensions impacting a country's readiness for a labour market transition are labour supply, institutional capacity, labour market flexibility and the relative attractiveness of relevant energy sectors. Table 1 describes the indicators which were incorporated and collated across countries.

Table 1: Labour Market Transition Potential Index.[8]

Dimension	Indicator	Effect on preparedness	Sources
Availability of Skilled Labour & Institutional Capacity	Share of population over 25 with at least a bachelor's degree or equivalent	+	World Bank
	Share of graduates from STEM programmes	+	UNESCO, OECD, World Bank
	Share of working age population with vocational education or training	+	ILO
	Share of all students in secondary education enrolled in vocational programmes	+	UNESCO
	Net migration as a share of population	+	World Bank
	Government spending on education	+	World Bank
	Female labour force participation rate	+	ILO
Labour Force Flexibility	Median age of population	-	UN
Energy Sector Attractiveness	Wage premiums in energy transition sectors	+	ILO and national statistical agencies

[8] To be included in the index, indicators had to be quantifiable and widely available across countries. This heavily constrained the possibilities. Many other relevant factors would impact real world outcomes but could not be incorporated in the analysis, for example, the presence of relevant active labour market policies and structured networks of cooperation between government and industry.

Availability of skilled labour & institutional capacity: Countries with a pre-existing high level of education in their labour force, as well as a high share of students enrolled in further education or training will be in a better position to supply skilled workers than those with a lower level of education. Equally, countries which prioritise education in their national spending are better placed. In terms of the renewable energy transition, existing strength in the fields of Science, Technology, Engineering and Mathematics (STEM) and in technical and vocational education and training (TVET), with a historical trend of students opting for these paths can enable a more rapid expansion of the occupationally relevant labour force. In addition, migration can be a key source of workers in the transition. Countries with more facilitative migration policies that can offer a quality of life to attract migrants, represented by a positive net migration rate, have an advantage in addressing the challenge of labour supply. Lastly, countries will benefit from cultures and institutions that promote labour force inclusiveness and do not exclude certain segments of the population from working. For example, a recent IMF study found that, after controlling for many confounding factors, a more equal treatment of women enables countries to transition their energy systems faster and at lower cost (Alexander et al., 2024).

Flexibility: Countries' capabilities to upskill and train workers through their education and training systems alone is insufficient to mobilise workers to transition to new sectors. The labour force also needs to be flexible enough so that workers have the desire and ability to learn the new skills required, as well as the willingness to change jobs and possibly also location. Occupational mobility tends to decrease with age. These qualities are more common to younger age groups (Bachmann et al., 2019).

Green sector attractiveness: To attract workers, jobs in renewable energy sectors must be 'good' jobs. In other words, the wages and working conditions of these jobs must be compelling enough to compete with the other sectors of the economy available to highly sought-after technically trained workers and graduates.[9] For the index, a higher wage level relative to the average wage in the economy is considered to increase the potential for workers and students to join energy transition sectors (Belot, 2022; Gallup, 2022).[10]

The index thus attempts to capture countries' underlying potential to supply skilled workers to sectors relevant to the green transition. For details of how the index is constructed, please refer to Section 5. The final index score ranges from 0 to 100, where higher values indicate greater labour market transition potential. The index is calculated for 19 countries, largely corresponding to the top global greenhouse gas emitters for the period 2014 to 2023 (see Figure 9).[11]

[9] The existence of a 'green wage premium' is a contested topic with conflicting evidence of its existence (Bircan et al., 2023; OECD, 2023b; Kuai et al., 2025; The Adecco Group, 2025). Many studies find a large premium, but they are subsequently largely explained away by education, experience, occupational and sectoral variation. This reflects the fact that many green transition jobs are in-demand, high skilled jobs requiring formal qualifications and therefore have higher wages compared to other lower skilled jobs. Overall, the evidence suggests that within sectors, green jobs do not command a significant wage premium relative to other occupations in the same sector. For the purposes of this exercise, we calculate wage premiums as the level of wages available in the most transition relevant sectors, relative to average wages in the country. This is calculated by dividing the local currency wages in the Utilities, Construction and Professional, Scientific and Technical Services sectors by the country's average wage. It is expected that higher wages in these sectors will attract future workers towards developing the required skillsets from other sectors, from abroad or encourage younger people to choose a career in the energy sector.

[10] Acute shortages of workers can lead to higher relative wage growth rates for a particular sector, which would indicate a low supply of workers. However, we consider wage levels, rather than wage growth, for the index. The structural and slower moving nature of relative wage levels in an economy aligns with the future-oriented perspective of the index, reflecting that wage levels are an important signal for students, migrants, and existing workers when they consider a job change.

[11] Including Australia, Brazil, Canada, China, Germany, India, Indonesia, Italy, Japan, Kenya, Mexico, Pakistan, Saudi Arabia, South Africa, Republic of Korea, Türkiye, United Kingdom, United States of America, Viet Nam. Some countries are not significant emitters but are included for regional representation.

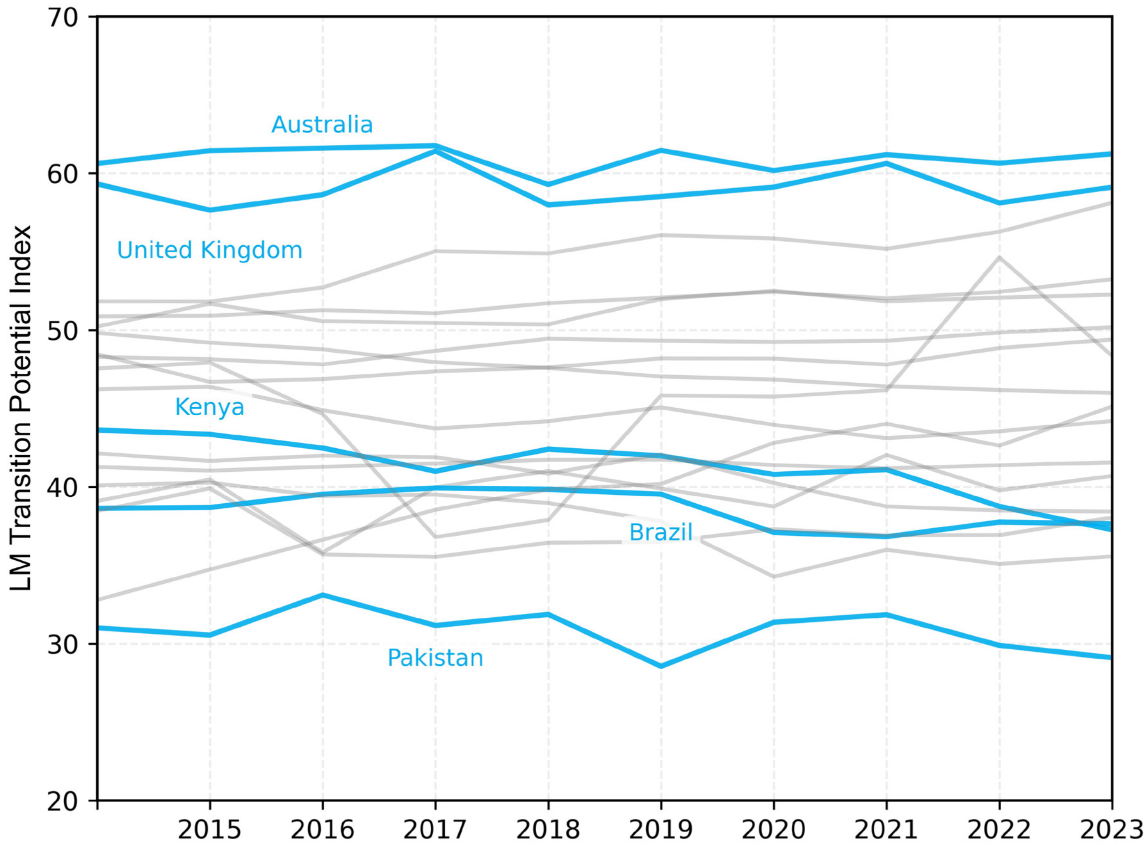

Figure 9: Labour Market Transition Potential Index over time for selected countries. The five countries highlighted were chosen for geographical representativeness while facilitating explanation of the differences in higher versus lower ranked countries. Results should not be interpreted as the actual supply of workers to energy transition sectors in these countries, but rather the theoretical capacity to supply workers based on factors found to be relevant in existing research.

The relatively fixed performance of countries over time is immediately apparent. This is influenced by the nature of many of the indicators, which reflect slow changing demographic conditions.

In addition, it is notable that no country ranks top across all categories of indicators with top scores close to 60, with a theoretically possible score of 100. This indicates all countries face challenges in supplying workers for their energy transition and these challenges are qualitatively different depending on national circumstances.

The two top performing countries throughout the period assessed are Australia and the United Kingdom (UK). Both countries rank highly in terms of the levels of tertiary education amongst the population, the share of workers with TVET qualifications and the share of students enrolled in vocational training, meaning there is a pool of workers with relevant skills within their economies. Both also rank close to the top of the group of countries in terms of net migration inflows. In addition, Australia, the UK and other high performing countries tend to dedicate substantial shares of government spending to education and feature high female labour force participation. However, these countries tend to perform less well on the flexibility measure with meaningfully older labour forces. This signifies larger shares of established workers who may be committed to competing sectors in the economy and less willing to engage in upskilling for new opportunities in renewable energy industries.

Interestingly, some high-income countries tend to rank lower in terms of relative sectoral wage attractiveness.

Both the UK and Australia rank close to the bottom for sectoral wage premiums in the utility and professional, scientific and technical sectors of their economies. This may be particularly relevant given persistent reports of labour shortages for renewable energy jobs in high income countries. In such economies, competition for technically skilled workers is high across multiple sectors of the economy, suggesting that wages may need to rise in the energy transition sectors to attract graduates and workers from competing sectors.

Most countries ranking further down in index performance face the disadvantage of regular net outmigration. They also tend to have lower levels of tertiary education in the population and lower shares of young people enrolled in vocational education. However, the wage premiums associated with energy transition sectors tend to rank comparatively highly, possibly reflecting less competition for technically skilled workers in these economies, for example through fewer available jobs in finance and digital technology industries which tend to attract technically skilled graduates in many high-income countries.
In sum, the index reveals the multidimensional nature of the challenges countries face in expanding their energy transition sector workforces. Effective policy response will require detailed understanding of the nature of the problem in the country in question so that solutions can focus on the correct objectives, whether that be investing in TVET training facilities or working with companies to facilitate skilled migration into the country.

To test the relevance of the index, its relationship with other variables was explored, namely wind and solar capacity levels and levels of GDP (see Figure 10).

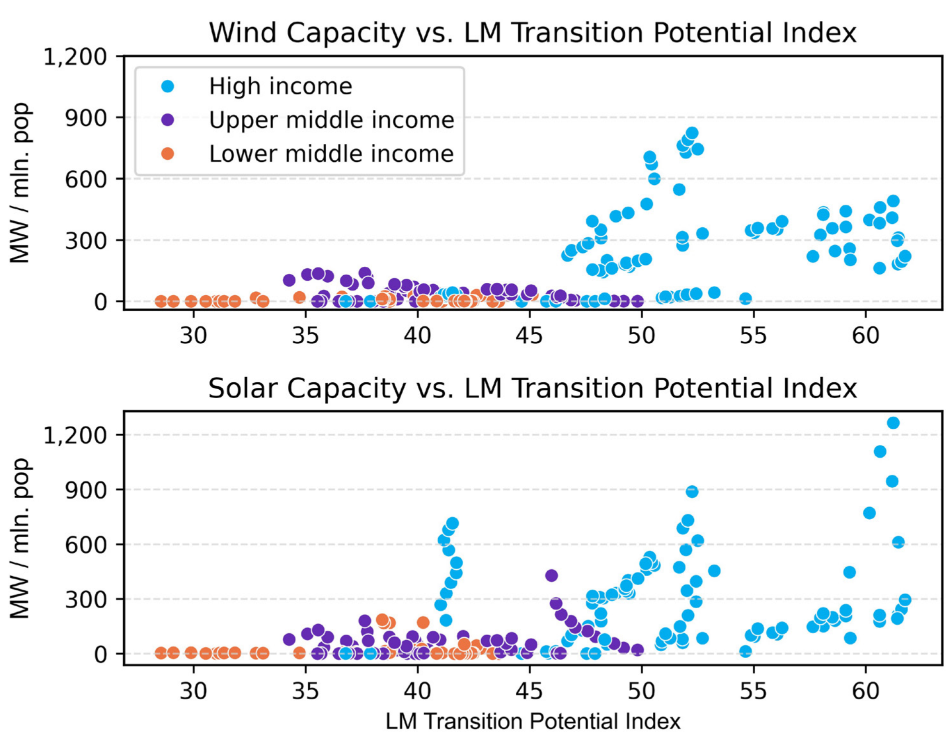

Figure 10: Correlations between the labour market transition potential index and wind & solar capacity. The charts show a scatterplot of megawatts of wind or solar capacity per million people plotted against the index score. Points are colour coded by income classification as per World Bank thresholds. A strong correlation exists between index scores and GDP per capita. Correlations between the index and wind and solar capacity are relatively strong. Data sources: wind and solar capacity (IRENA), population (UN Population Statistics), GDP per capita (World Bank).

Relatively strong correlations exist between renewable energy capacities and index performance.[12] In addition, simple linear regressions show the index to be predictive of relative wind and solar capacity. As indicated by the colours within each plot, the effect is strongly mediated by levels of economic development.[13] These relationships substantiate that the index scores are capturing real information about countries' labour markets. The strong association with GDP suggests a mutually reinforcing relationship between economic output and a country's ability to mobilise a labour market transition for their energy transition. Thus, investing in labour markets and training facilities to support the energy transition also supports economic development.

The results shown in Figure 10 imply an additional interesting insight. The stronger correlations between wind power capacity and the labour market transition potential index, compared to solar power, may point to the relative ease with which solar power capacity can now be erected, when the right incentives are in place. Low cost and ease of construction combine to make modern solar power a transformative technology as, for example, evidenced by Viet Nam's addition of 9 GW of solar power in just one year in 2020, more than doubling the previously installed capacity (Gunther, 2021).

Overall, the factors underlying relatively lower scores are changeable and can be improved. Insufficient education levels and training facilities are surmountable challenges, with dedication of necessary funding and resources. Improving technical training facilities, education levels within the population and supporting the creation of incentives attractive to companies and workers to participate in the energy transition not only accelerates emission reductions but also broadly benefits economic development while enabling people to fulfil their potential. The much younger age profiles common to most of the lower ranked countries also highlights the flexibility available if sufficient resources can be dedicated to the challenge of training the labour force.

[12]Linear (pearson) and non-linear (spearman) correlation coefficients are calculated between the index and wind and solar per capital levels. Relatively strong correlations exist, from 0.61 & 0.64 for linear and non-linear correlations between the index and wind capacity to 0.5 & 0.61 for correlations between the index and solar capacity. The linear correlation coefficient between the index scores and annual GDP per capita is very strong at just below 0.8.

[13]Simple linear regressions were run with wind and solar capacity as the outcome variables and the index as the sole explanatory variable. This exercise showed the index to be a statistically highly significant predictor of relative wind and solar capacity levels. However, as this is not a rigorous statistical assessment and given the index is strongly correlated with GDP results should be interpreted cautiously. This is because GDP also correlates with other important factors for renewable energy development, for example, government fiscal capacity and financial market development.

4 Moving Forward

To avoid climate damaging delays in the power sector transition, skilled labour shortages must be acknowledged as a key structural barrier and provided with the necessary focus by policy makers. This study has demonstrated how shortfalls of skilled workers in the power sector can quickly compound and lead to real world consequences. Deficits of workers and skills lead to lower levels of renewable energy capacity and higher levels of emissions which translate into greater climate damages and the accompanying human suffering.

Given the time required to train and mobilise a skilled workforce, and the risk of shortages compounding over time, strategic, forward-looking planning is essential to ensure that labour supply keeps pace with the demands of the energy transition.

The study also demonstrates the multidimensional challenge of the labour force transition required to enable the energy transition. Different types of countries face different barriers in meeting the labour supply needs of their respective energy transitions. Developed economies largely have the stock of skills and the institutions needed to train workers into renewable sectors. However, tight labour markets and competition from other sectors are likely leading to labour shortages at present. Overcoming these challenges may require higher wages in transition sectors, policy stability signalling durable careers and good working conditions in energy sector jobs to attract new graduates. Companies can also utilise migration as a source of workers and demonstrate their willingness to capture the benefits of the energy transition by hiring and upskilling underqualified workers. Governments, in turn, can support the creation of accelerated industry conversion courses in targeted sectors. Meanwhile, emerging economies have clear potential to further develop technical educational facilities in their countries and increase government spending and focus on labour force upskilling. Collaboration between industry and government to conduct skills-needs forecasting and develop relevant education and training opportunities can position countries well. Faced with the disadvantage of regular outflows of skilled workers, emerging economies can seek to develop mutually beneficial migration pathways with partner countries and companies experiencing labour shortages, to provide training and support for their young labour forces, in the expectation that they will return.

Ultimately, ensuring a sufficient workforce to deliver the energy transition will require coordinated action across education, employment, and migration systems, tailored to countries' unique demographic and institutional contexts. Effective measures will need to be calibrated to each country's circumstances and target specific barriers slowing the entry of different categories of workers. These measures need to be reassessed regularly to reflect changes in, for instance, domestic value chains, automation and evolving skill needs. If companies and governments fail to rise to the challenge, climate goals will go unmet.

5 Technical Annex - Data & Methodology

Labour Force Shortage Modelling

To assess the cascading risks of workforce constraints, we developed an exploratory global model of labour demand and supply in the power generation sector. The model simplifies labour market dynamics and their impact on power generation capacity development, using broad regional aggregates. The results should be understood as stylised, illustrative scenarios that do not have real predictive power, but instead highlight how labour shortages in the renewable power sector could trigger far-reaching consequences for the global energy transition and the Paris Agreement temperature goals. The following section outlines the methodology and its limitations in more detail.

Primary input data and scope

The primary inputs of our model are power capacity and generation data, disaggregated by technology and broad region, taken from the IEA's World Energy Outlook (WEO) (2024) (see Table 2).

Table 2: Modelling scope overview.

Technology breakdown	Geographical breakdown
Coal: without Carbon Capture Utilisation and Storage (CCUS)	North America
Natural gas: without CCUS	Central and South America
Fossil fuels: with CCUS	Europe
Oil	Africa
Nuclear	Middle East
Hydrogen and H2-based fuels	Eurasia
Modern bioenergy and renewable waste	Asia Pacific
Hydro	Southeast Asia
Solar PV	
Wind	
Battery storage	

The WEO's APS scenario is the base scenario of our model. It projects power capacity and generation if countries achieve all national energy and climate targets, including net-zero targets. We also use the APS scenario to describe a pathway roughly in line with the global target to triple renewable energy capacity by 2030. In reality, the APS scenario falls slightly short of the global target to triple renewables (Enterprise, 2024), but it is sufficiently close for the purpose of this study (our modelling shows a 2.97-fold increase in renewable capacity between 2022 and 2030). We do not use the WEO's Net Zero (NZE) scenario for this analysis, although it is best aligned with the Paris Agreement targets, as it would yield labour force estimates that are largely disconnected from current government plans and pledges, offering limited practical insight. The WEO's Stated Policies (STEPS) scenario, which approximates a business-as-usual trajectory, is referenced for comparison only.

Labour demand estimation

Labour demand is derived by combining annual capacity additions and retirements, disaggregated by technologies and regions, with regionally adjusted employment factors from Rutovitz et al. (2015) and Ram et al. (2022).

The idea behind this approach is to multiply unit-specific activity levels (e.g. installed capacity and electricity generation) by region-, technology-, and value chain-specific employment factors that reflect local labour intensity, productivity, and supply chain characteristics. Applying these employment factors to the WEO's APS capacity additions allows us to estimate the labour force required for the global power generation sector over the modelling period (i.e. the Labour demand (APS) scenario), disaggregated into Manufacturing, Construction & Installation, Operation & Maintenance, and Decommissioning phases. Regional adjustment of employment factors attempts to capture differences in local content in these phases.

We partially capture changes that affect labour force needs per unit-specific activity level over time through learning curves. These curves employ learning rates for renewables and fossil fuels with CCUS from the IEA (2024), which range from 1%-20% over the course of the modelling period. These rates are extremely crude approximations and likely incomplete, but currently without alternatives. Indeed, automation may have much stronger impacts in the near term, which will heavily decrease labour force needs, but for which there is currently no empirical basis to incorporate in our model.

While the use of employment factors is a widely accepted approach to estimate labour needs, and our method incorporates regional differentiation and technology learning to reflect contextual variation, important limitations remain. Employment factors do not fully capture heterogeneity in labour market conditions or future shifts in job profiles. Moreover, regional or temporal dynamics in labour demand are difficult to model accurately. Further, the employment factors used in this analysis are slightly outdated (from 2015), and recent updates provided by the original author for Australia (see Rutovitz et al. (2025)) show significant reductions in labour force needs per MW for renewable energy technologies. It is therefore likely that our analysis overestimates the true labour force needs to some extent. Taking 2022 as a reference year, for example, IRENA and ILO (2024) estimate a total renewable energy labour force of about 13.7 million people, while the IEA (2023) put total clean energy sector jobs at 35 million. Using employment factors, we estimate the renewable power sector to employ about 19.8 million people in 2022, significantly more than IRENA and ILO (although we include a larger technology catalogue) and much less than IEA (who includes a much broader scope). To test the sensitivity of our results to lower employment factors, we ran the model using updated figures for Australia from Rutovitz et al. (2025). This produced significantly lower global renewable energy labour estimates than those from IRENA and ILO (2024), which we consider unrealistic. The Australian values are likely not representative globally and therefore result in underestimation when applied worldwide.

Labour shortage estimation

To explore how delayed workforce mobilisation may affect the renewable power generation capacity development, we define an exploratory delay scenario (DLY). In the model, we define the share of additional labour demand that can be met each year via a workforce adjustment coefficient. Labour supply (LS) is then modelled based on labour demand (LD), using a partial adjustment function that incorporates the workforce adjustment coefficient (λL) (Equation 1), representing a gradual convergence towards APS-level demand.

Equation 1: Partial adjustment function for labour supply.

$$LS_t = LS_{t-1} + \lambda L * (LD_t - LS_{t-1})$$

The workforce adjustment coefficient is a central but uncertain parameter. While some empirical studies analyse labour market adjustment speeds (e.g. David et al. (2020) finds adjustment coefficients ranging between 20% and 40% for Latin America), no reliable global estimates exist for the power generation sector that could be generalized for our analysis.

An exploratory approach is thus adopted, assuming a coefficient range of between 20-60%, that is adjusted by technology and region, based on expert judgement (we find the 40% upper bound in the reference given above unrealistically low). We also provide a DLY-FAST and DLY-SLOW scenario, for which we assume that labour forces respond fast (60%) in all regions and slow (20%) in all regions, respectively.

A further limitation is the assumption that the coefficient remains constant over time. In practice, policy reform, training expansion, rising wage incentives, technological change, demographic shifts, labour market regulations, and social or cultural factors could reduce structural barriers and accelerate workforce alignment. While more dynamic modelling is theoretically possible, it would require additional assumptions that introduce complexity without robust empirical foundations. It would require, among other things, fully endogenizing labour demand feedback effects in response to labour shortages, which would significantly increase model complexity without having firm empirical foundations.
To estimate the educational composition of the workforce required to address the labour shortages, we combine data on occupational shares for renewable technologies from Rutovitz et al. (2025) with information from Solar Career Map (IREC, 2025) and Wind Career Map (U.S. Department of Energy, 2025) on the desired education levels for relevant occupations. Due to data availability constraints, the scope is limited to solar and wind technologies and focusses specifically on Construction & Installation and Operations & Maintenance (excluding Manufacturing and Decommissioning). This estimation therefore represents a snapshot of just a part of the total renewable energy workforce. We apply occupational shares to the modelled labour shortage, using the simplifying assumption that the occupational composition of labour demand translates one-to-one to the occupational composition of the shortage. As such, this approach does not constitute a projection based on current workforce education levels or reported occupational shortages. The occupations from Rutovitz et al. (2025) are matched to the databases of the Solar Career Map and Wind Career Map to derive the desired levels of education.

Capacity delay estimation

Next, we explore the implications of annual labour shortages on actual generation capacity deployment. We combine the prevailing labour shortage (θt) with a capacity development adjustment coefficient (λC) and the capacity additions pledged in the APS scenario (CAt) to estimate adjusted capacity additions in the partial adjustment function in Equation 2.

Equation 2: Partial adjustment function for capacity development.

$$C_t = C_{t-1} + \lambda_C * \theta_t * (CA_t)$$

The adjustment coefficient for capacity development is used to define the responsiveness of capacity development delays to labour shortages. Again, the literature offers very limited insights into coefficients that can be generalised globally. We assume that the responsiveness ranges between 85%-105%. In some cases, moderate labour shortages may be absorbed through overtime or flexible work arrangements, i.e. up to 5% can be absorbed. In other cases, even small shortages in critical occupations may stall entire projects, i.e. reducing capacity additions by up to 25%. We implement regional- and technology-specific adjustments to the capacity development adjustment coefficient, which results in coefficients of between 90%-100% for most region and technology combinations. The DLY-FAST and DLY-SLOW scenarios model the combined impact of labour force responses across all regions, fast (60%) and slow (20%), respectively, alongside assumptions of very responsive (85%) and not very responsive (105%) capacity adjustments. This produces a large range of possible scenarios and reflects both the uncertainty and compounding impact of slow or fast adjustments.

Power generation mix and emissions pathway estimation

Using the adjusted generation capacity values, we estimate electricity generation under the DLY scenario. Total electricity demand is held constant at APS levels, but the shortfall in renewable generation is substituted with generation from existing capacity, primarily fossil fuel-based sources. The approach to estimating which technologies substitute for delayed renewables is highly simplified and does not reflect cost- or merit-based power sector modelling. Instead, we base assumptions on average load factors and the regional prevalence of generation technologies to estimate which sources are likely to meet excess demand. A key limitation is that this method does not account for ongoing shifts away from coal towards lower-emission technologies (e.g. gas).

Finally, emissions trajectories are calculated by combining the generation data with emissions factors from the IEA (2021) and Schlomer et al. (2014). For broadly defined technologies such as modern bioenergy and renewable waste, aggregated emissions intensity can vary significantly. We identify this as the main reason for any differences in global emissions levels between our results and those of other studies.
This study does not model temperature pathways explicitly. Instead, we reference the temperature outcomes associated with WEO scenarios and specifically use the STEPS scenario to provide a reference range. The APS scenario aligns with a temperature increase of approximately 1.7°C in 2100 (IEA, 2024). The STEPS scenario is associated with global warming of up to 2.4°C in 2100 (IEA, 2024).

The workforce adjustment coefficient, which determines how quickly labour supply can respond to rising demand, is not empirically known at the global level for the power sector. Similarly, the relationship between labour shortages and renewable energy capacity development, the capacity development adjustment coefficient, is highly uncertain, context dependent and not empirically known.

Labour Market Transition Potential Index

The labour market transition potential index was constructed following established methodological approaches similar to those employed by the UN's Human Development Index (UN Data, 2010) and the OECD Environmental Policy Stringency Index (Kruse et al., 2022). Best practice technical guidelines were followed for the construction of the index (Nardo et al., 2008).

The index combines multiple indicators across three key dimensions that theoretically contribute to a country's capacity to supply workers for energy transition sectors: availability of skilled labour and institutional capacity, labour force flexibility, and energy transition sector attractiveness. Indicators were selected where evidence for their relevance as a predictive indicator of the green workforce was found, as explored in Section 2, or if there is a theoretically strong case for their inclusion. The exercise was naturally constrained by data availability. The index thus attempts to capture the macro-institutional capacity of a country to supply sufficient workers to the energy transition, rather than the more micro focus taken in other research, which focuses on the granular task-based skill levels of the existing workforce within a country (Tyros et al., 2023).

Raw data for each indicator specified in Table 1 was collected for the period 2014 to 2023. Data was collected for the largest carbon emitting countries in the world with some changes made to this list reflecting geopolitical events and to add other countries in the analysis for more complete geographical representation. The final list totals 19 countries. The year 2024 was excluded due to insufficient data availability across the indicator set. The dataset encompasses indicators drawn from multiple international sources including the World Bank, UNESCO, OECD, International Labour Organization (ILO), and national statistical agencies.

Imputing Missing Data Treatment

The analysis encountered two distinct categories of missing data, each requiring different imputation strategies. The first category consisted of country-variable combinations where data was available for some years but missing for others within the study period. For these cases, a systematic approach was employed to determine the most appropriate imputation method:

Where sufficient data points existed, the presence of a significant temporal trend was assessed using linear regression analysis. Specific thresholds for R-squared values, p-values, and minimum data point requirements were established to determine the legitimacy of observed trends.[14] When a statistically significant trend was identified, linear regression was used to predict missing values. In cases where available data exhibited fluctuation rather than clear directional movement, or where insufficient data points prevented reliable trend analysis, missing values were imputed using the country-specific variable average across available years.

Prior to all trend and average calculations, outliers were identified and removed using the standard definition of values exceeding 1.5 times the interquartile range beyond the first and third quartiles.

The second category of missing data comprised entire country-variable combinations where no data could be sourced from reputable national or international databases. For these cases, missing values were imputed using the annual average for the respective variable across all countries within the same income group classification, using the World Bank's classification of 2023 income per capita. This category of missing data accounted for 6% of data points. It occurred for countries across all three income groups and regions included in the analysis and so should not impose a systematic bias to the results.

[14] Threshold were set at a minimum R2 of 0.3, at least 4 data points and the resulting coefficient having a minimum p-value of 0.1.

Index Specification and Validation

Multiple methodological approaches were tested to determine the final index construction method. Both standard normalisation and min-max normalisation techniques were applied to create different versions of the index. Additionally, equal weighted indices were compared against different combinations of weighted averages. Versions incorporating extreme value adjustments were also calculated where values were reset to fall within the 95th percentile range of the distribution, i.e., data points which fell outside the 2.5 to 97.5 percentile range were reset to the end points of the range.

To assess potential multicollinearity concerns, principal components analysis was also performed on the complete set of indicators. This analysis examined whether strong correlations among variables posed methodological challenges for index interpretation and validity.

The various index specifications were tested through correlation analysis with theoretically relevant outcome variables, mainly wind and solar energy capacity levels and various iterations of these including growth rates, annual changes and lagged relationships. It was discovered that the index correlated strongly with GDP per capita during this process and so regressions with GDP per capita as a control variable and potential outcome variables were also carried out.

The results of this verification exercise were considered with theoretical justification and questions of interpretability. For example, the principal components analysis revealed that while PCA techniques did not improve correlations with validation variables, the derived components also failed to create theoretically meaningful relationships with original variables which reflected the conceptual framework underlying the index.

Final Index Specification

The results presented in this report are derived from a weighted averaging approach with min-max normalisation. The selected methodology demonstrated superior performance in validation exercises while maintaining theoretical coherence and interpretability.

The chosen weights are very close to an equal weighted index. The three sector wage premium indicators are first combined into one variable.[15] The labour supply and institutions category is then very slightly overweighted - seven indicators are given a weight of 0.8. The flexibility dimension, which is composed only of median age, is then given a weight of 0.1. This combination was found to have slightly stronger correlations with theoretical outcome variables and improved interpretability compared to an equal weighted index of 9 variables by making the range of scores 0 to 100.

To calculate the index scores, all variables are standardised with min-max normalisation. These standardised measures are then averaged within each of the three dimensions. The dimension-specific weights are subsequently applied to derive the final index score, where higher values indicate greater labour market transition potential.

This methodology ensures that the index captures the multidimensional nature of labour market readiness for energy transitions while maintaining comparability across countries and over time.

The following chart indicates the results of the exercise for 2023.

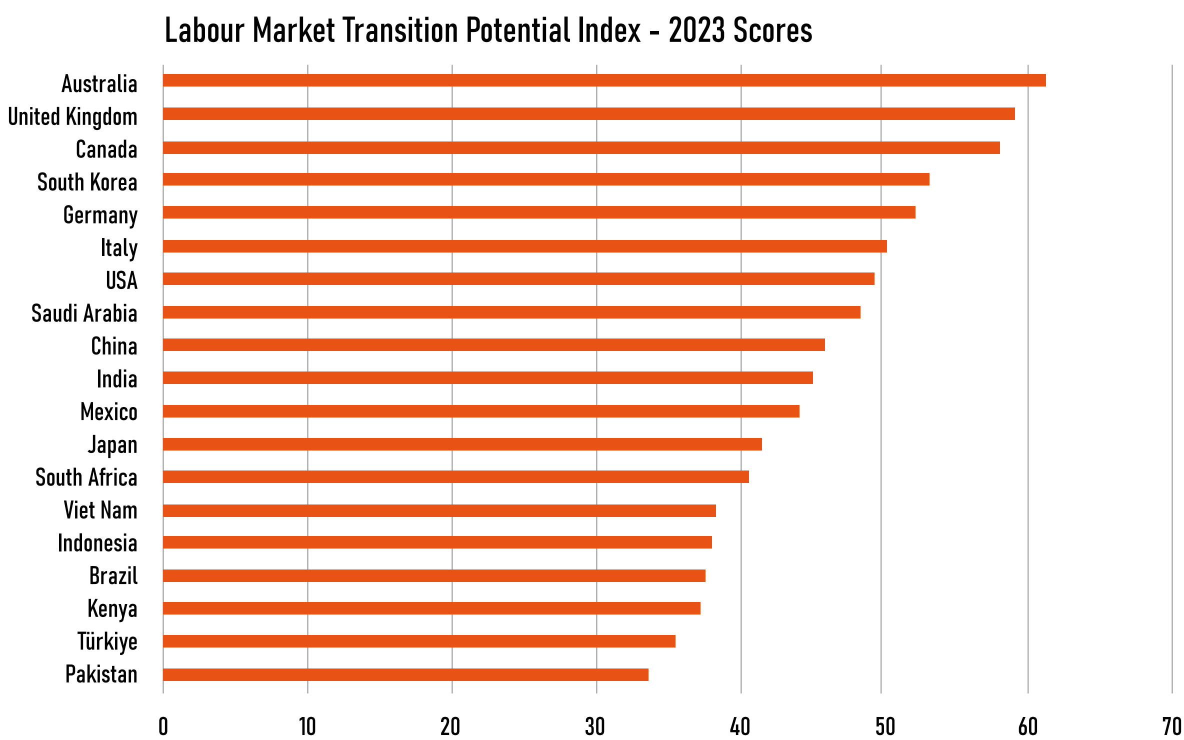

Figure 11: Labour Market Transition Potential Index for all computed countries in 2023. Results should not be interpreted as the actual supply of workers to energy transition sectors in these countries, but rather the theoretical capacity to supply workers based on factors found to be relevant in existing research.

[15] The relatively low weight afforded to this dimension also reflects the imperfect way it is measured, refer to Section 3 for further discussion.

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Deutsche Gesellschaft für
Internationale Zusammenarbeit (GIZ) GmbH

Sitz der Gesellschaft / Registered offices
Bonn und Eschborn / Bonn and Eschborn

Friedrich-Ebert-Allee 32 + 36
53113 Bonn, Deutschland / Germany
T +49 228 44 60-0
F +49 228 44 60-17 66

Dag-Hammarskjöld-Weg 1 - 5
65760 Eschborn, Deutschland / Germany
T +49 61 96 79-0
F +49 61 96 79-11 15

E info@giz.de
I www.giz.de