Journal of Vasyl Stefanyk Precarpathian National University
http://journals.pnu.edu.ua
Vol. 12, No. 4 (2025), 112-124

doi: 10.15330/jpnu.12.4.112-124

ISSN 2311-0155 (Print)
ISSN 2413-2349 (Online)

STRUCTURAL TRANSFORMATIONS OF EMPLOYMENT IN GLOBAL ENERGY IN THE CONTEXT OF TRANSNATIONALIZATION OF LABOR RESOURCES PROVISION

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Abstract. The article examines the structural transformations of employment in the global energy sector in the context of the transnationalization of labour supply. It is established that, in the clean energy sector, employment growth has outpaced total employment growth worldwide. It has been determined that, as a result of large-scale investments, the number of people employed in clean energy has exceeded that of jobs in fossil fuels. It is emphasised that since most jobs in the energy sector can't be transferred abroad, the role of the transnational factor in the development of the energy sector is growing. The international scale of labour use characterises these sectors and is a key source of employment in every world region. Global trends in energy development shape the prospects of energy transnational companies, and the number of jobs crucially depends on the pace of the transition to clean energy. At the same time, the limited supply of workers with the necessary qualifications on the energy labour market creates high competition for employees, putting energy TNCs in the position of having to provide labour through labour retraining. It is concluded that the labour supply in the clean energy sector and the solution to the problems of fossil fuel sector workers require a comprehensive approach at the international, national, and company levels, including developing the necessary skills and providing appropriate institutional support.
It is proven that the transition to green energy is closely linked to employment policy, as it entails significant changes in the energy sector's job structure, requiring a comprehensive approach at all levels to retrain and further employ displaced fossil fuel workers. As a result of the research, a Conceptual and structural model of the transnationalization of labour resource provision in the global energy sector was developed, reflecting the systemic integration of labour resources in the worldwide energy sector, driven by global economic and technological changes.

Keywords*:* employment in global energy, clean energy sector, energy independence, transnationalization of labour resources provision, global labour market, skills development ecosystem, professional development.

JEL Classification: J21, Q43, F66

1. INTRODUCTION

Meeting the challenges of the energy transition by 2050 requires an adequate labour supply in the energy sector. The development of clean energy has created a strong demand from energy companies to attract employees to the sector. At the same time, staff shortages and limited national labour markets have led to supply chain disruptions across many segments of the energy sector, including offshore, wind, and energy efficiency modernisation (IEA 2022), which may negatively affect the industry's prospects as a whole. In addition, worker dismissals in the fossil fuel sector are becoming increasingly

urgent, exacerbating labour market imbalances.

Accordingly, as the world transitions from fossil fuels to renewable energy sources, there is a growing need for a holistic approach to ensuring the energy transition, taking into account not only technological aspects but also the international scale of socio-economic consequences (IRENA 2023), given the transnational nature of the activities of leading energy companies.

2. RESEARCH METHODS

The purpose of the article is to identify and assess the structural transformations of employment in the global energy sector caused by the worldwide energy transition, with a special emphasis on the role of transnationalization in shaping the supply of labor resources and identifying key challenges and mechanisms for adapting the workforce to the new requirements of the "green" economy.

To achieve the research objective, the following methods have been used: the process of comparative analysis was used to compare different scenarios of energy sector development, which allowed us to predict changes in the structure of the workforce; the technique of system approach was used to consider the energy sector not as a collection of discrete elements, but as a holistic system undergoing structural transformation; the method of statistical analysis was used to process and interpret quantitative data presented in the text and figures; the method of institutional analysis was used to examine the role and influence of international organizations (ILO, IEA, IRENA) and national governments (EU, US, UK programs) on the formation of employment policies in the energy sector.

3. RESULTS AND DISCUSSION

Global trends in employment restructuring in the energy sector.

A sign of the current stage of economic development is the structural transformation of the energy sector towards the dominance of renewable energy sources. According to the global REMap roadmap developed by the International Renewable Energy Agency (IRENA 2020), the share of renewable energy in the energy sector should increase from 25% in 2017 to 85% in 2050. By 2050, renewable energy sources could account for more than 60% of total final consumption in many countries, which is 2.5 times the current level (Kalinina et al., 2021).

The socio-economic aspect of the transition to low-carbon energy sources is reflected in the transformation of the employment structure for fossil fuel workers and their communities. This is a key social dimension of the energy transition to low-carbon energy sources to mitigate global warming (Maissa, Saloua-Nassima & Heffron, 2025; Pai, Harrison & Zerriffi, 2020). According to (Klepacka, 2022), the main reasons for the transformation of employment in the energy sector are incentives through EU support programs and the development of new technologies (e.g. biomethane and heat pumps), which contribute to job growth; while the reduction in employment is caused by plant closures, the introduction of high-efficiency installations, as well as high initial investment costs and strict regulatory standards (Kozar & Sulich, 2023). Research also suggests that transformations in the energy sector go beyond technical aspects such as energy sources and technologies. They also encompass economic, political (energy security) and social dimensions (Kozar & Sulich, 2023). Recent research on energy employment transformations highlights that educational institutions, students, workers, and others who make choices that will enable the changing and growing workforce to make the energy transition a reality need to know not only the number of jobs but also the specific occupations that are needed (Rutovitz et al., 2025).

Total investment in clean energy grew by 32% between 2019 and 2022, with more than a third of this growth occurring in 2022, driven by increased government financial assistance packages and the rapid expansion of clean energy supply chains. Increasing the share of renewable energy sources distributed territorially for the implementation of long-term government support also contributes to the formation of an energy balance without external energy supply to achieve SDG, environmental, social (including

job creation) goals, etc (Shtunder et al., 2022). The development and implementation of renewable energy sources are essential components of EU energy security (Khadzhynova et al., 2023). As a result, the growth rate of employment in the energy sector globally outpaced the growth rate of total employment: while jobs in the global economy in 2022 fell 1% short of the level of 2019 (World Bank 2022), the number of jobs in the energy sector grew by more than 5% and amounted to 67 million jobs in 2022, or 3% of global employment (2019 - 65 million and 2% of international jobs, respectively) (Fig. 1). This growth was almost entirely driven by the clean energy sector, where employment increased by more than 15% in 2019-2022, while the number of jobs related to fossil fuels decreased by 4% (IEA 2023).

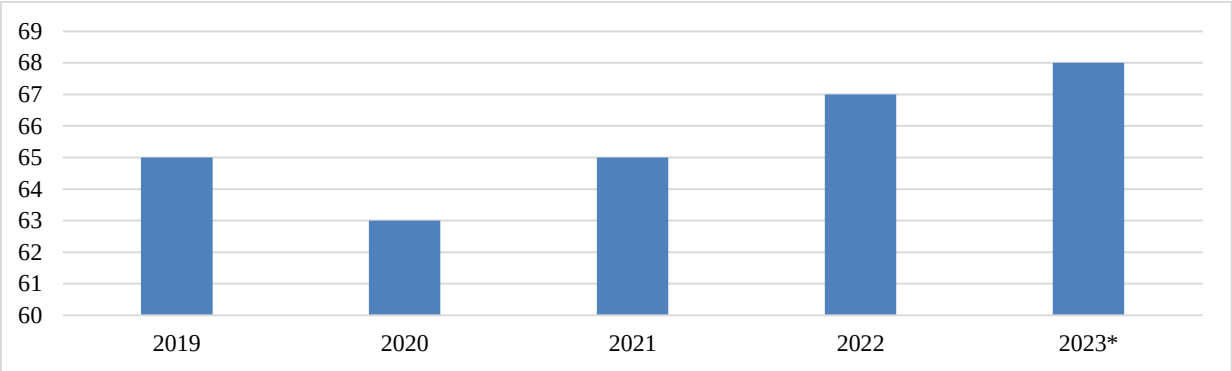

Fig. 1. Total global energy employment, 2019-2023, [jobs in million] workers (* forecast)*
Source: IEA 2023

Of the 67 million people employed in the energy and related industries in 2022, almost half of them were in the clean energy sector. As a result of large-scale investments in this sector (Fig. 2), the number of people employed in clean energy exceeded that of jobs in fossil fuels in 2021 (Fig. 3).

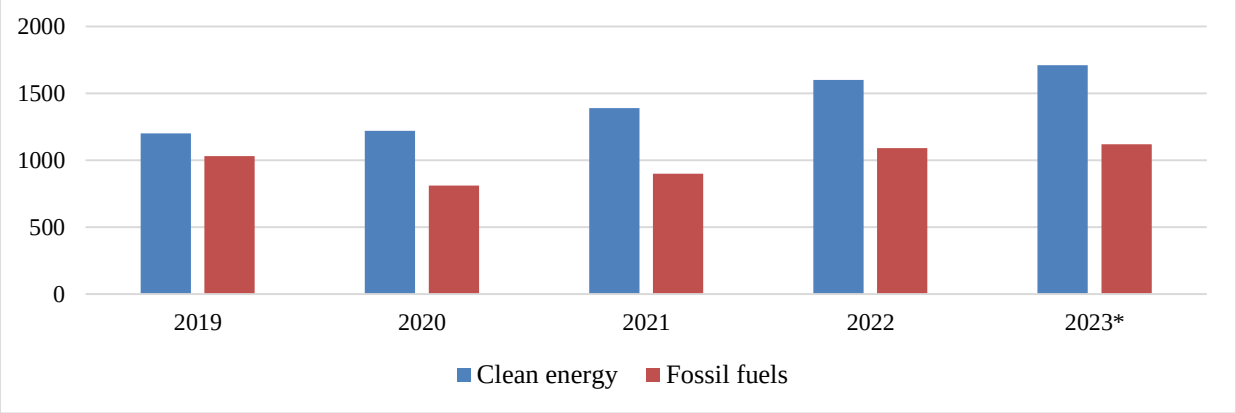

Fig. 2. Global investment by sector, 2019-2023, [billion USD] (* forecast)*
Source: IEA 2023

Employment growth in clean energy is driven by the development of the renewable energy sector, with solar, photovoltaic, and wind power plants accounting for 60% of that growth. In 2019-2022, employment in solar energy increased by 30%, in the production of electric vehicles and batteries by 148%, in wind energy by 20%, in the extraction of critical minerals by 27%, and in heat pumps by 27% (IEA 2023).

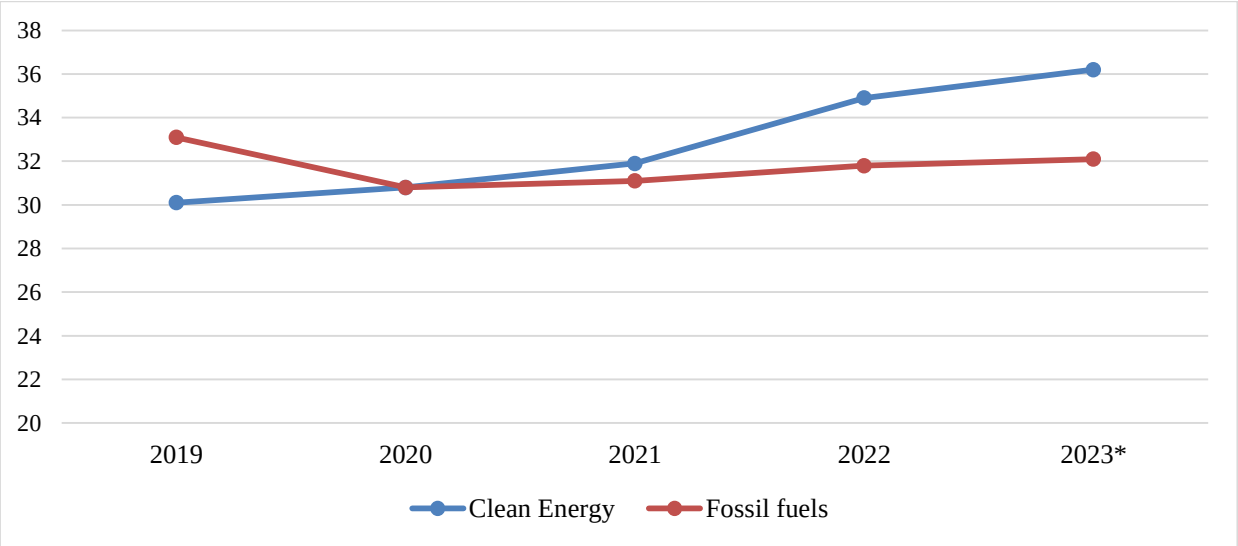

Fig. 3. Total energy employment, by sector, 2019-2023, [jobs in million] (* forecast)*
Source: IEA 2023

In general, jobs in the energy sector cover the entire value chain: extractive industries (8.5 million), electricity generation (21 million), construction of new energy infrastructure (14.5 million), operation and maintenance of energy supply systems (14.5 million), and other jobs (7.5 million) (Fig. 4). The detailed structure of employment in the global energy sector in Fig. 5 shows the dominance of clean energy in the industry structure on a worldwide scale.

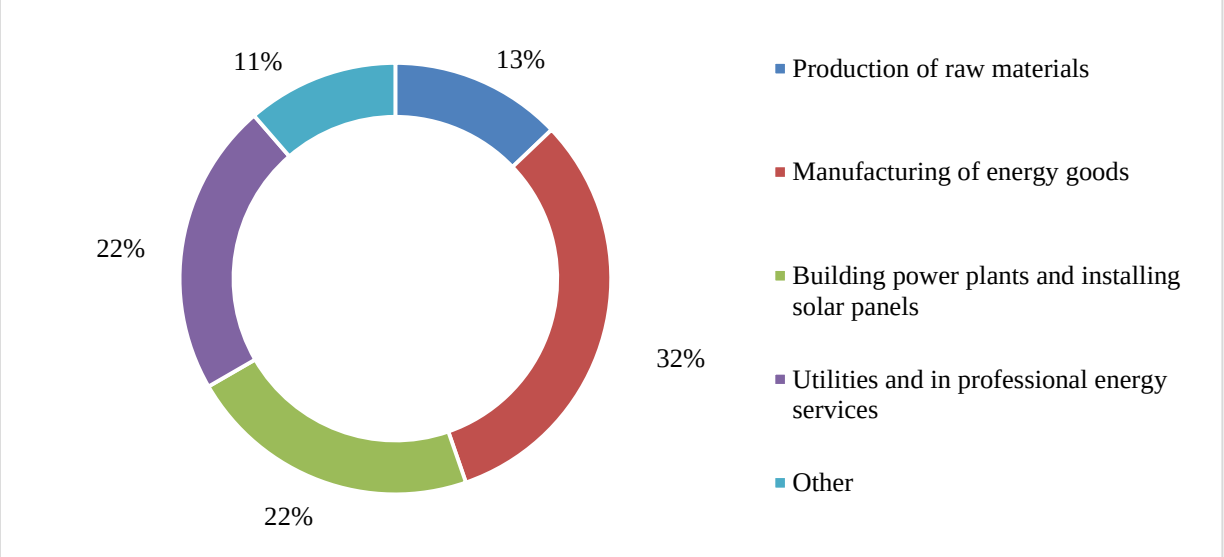

Fig. 4. Employment structure in the energy by sector, 2022, [%]
Source: World Bank 2022

According to the International Energy Agency (IEA), in 2024, the total volume of investments in the energy sector will exceed USD 3 trillion for the first time. About 2 trillion US dollars will be directed to the production of energy from renewable sources, the creation of energy storage systems, carbon-neutral fuels and the production of electric vehicles, more than 1 trillion - to the production and storage of gas, oil and coal (Guardian, 2024), which indicates that the trend of structural employment transformation in the energy sector will continue in the future.

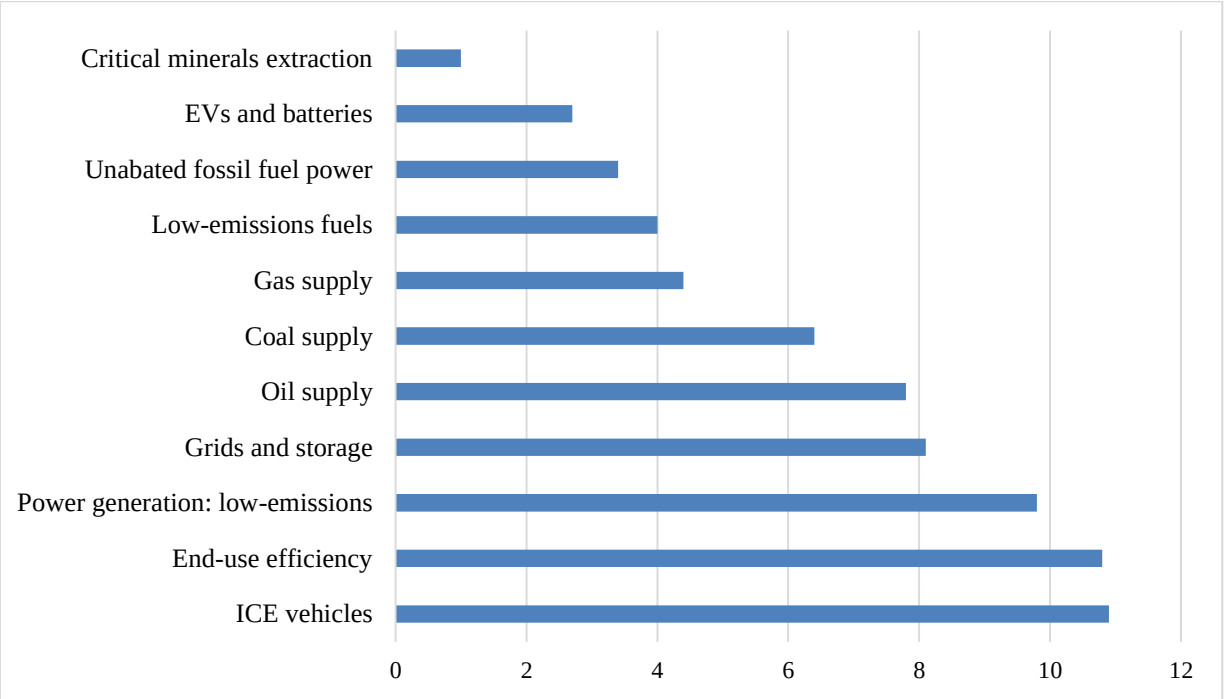

Fig. 5. Global energy employment in selected sectors, 2022, [jobs in million]

Source: IEA 2023

Transnational aspects of labour supply in the energy sector.

The transnationalization of labour supply is extremely important for the development of the energy sector. Although energy is a global industry, about 60% of jobs are located where energy facilities are built and operated (IEA, 2023). Even if the products are sold on international markets, production and related jobs are concentrated mainly in certain regions. For example, China, the United States, Europe, Japan, and Korea are home to powerful production centers that are home to multinational companies that play a key role in international energy supply chains: China is the base for large supply chains of solar photovoltaic systems and batteries, the United States is home to multinational oil and gas companies, and Japan, Germany, Korea, and Denmark are home to a significant share of TNCs' capacities for the production of energy equipment such as turbines, power electronics, and vehicles.

The leading factors determining the location of jobs in the energy sector are labour productivity, wages, and investment in the region's new energy infrastructure. Accordingly, two-thirds of production capacities and jobs are located in countries with a lower level of economic development, and one-third in developed countries: North America - 7.1 million workers, Central and North America - 4.2 million workers, Europe - 7.7 million, Africa - 4.3 million, China - 19.3 million, India - 8.4 million, Oceania - 8.7 million, Middle East - 3.9 million, Eurasia - 2.9 million jobs (Table 1). Since most jobs in the energy sector cannot be transferred abroad, the role of the transnational factor in the development of the energy sector is growing: the fuel, electricity and end-use sectors, characterised by the international scale of labour use, are key sources of employment in every region of the world.

The prospects for energy TNCs are determined by global trends in the energy sector, and trends in job numbers depend crucially on the pace of the transition to clean energy. Today, there are two scenarios for the development of the energy sector and, accordingly, the formation of the labour force structure in the industry:

- *Stated Policies Scenario (STEPS)* – the 2030 energy sector development scenario, which takes into account the relevant energy policies and implementation measures adopted as of the end of August 2023. The bottom-up modelling for this scenario requires a large number of sectoral details, including pricing policies, efficiency standards and schemes, electrification programs, and specific infrastructure projects.

Tab. 1

Energy employment by region and sector, 2022, [jobs in thousands]

Sector	North America	Central and South America	Europe	Africa	China	India	Other Asia-Pacific	Middle East	Eurasia	Global
Supply: coal	100	100	100	100	3100	1600	700	< 50	300	6200
Supply: oil and gas	1700	1000	700	1300	1100	800	1100	2800	1300	11700
Supply: low-emissions	200	900	300	600	500	600	600	< 50	100	3700
Power: generation	1000	800	1500	600	4500	1300	1900	400	400	12500
Power: grids	1000	400	1000	400	2200	1600	800	200	200	8000
End uses: vehicles	1800	600	2400	200	4300	1300	2000	200	300	13100
End uses: efficiency	1400	300	1600	500	3500	1200	1600	200	200	10700
Critical minerals	100	100	< 50	400	< 50	< 50	100	< 50	100	800
All energy	7100	4200	7700	4300	19300	8400	8700	3900	2900	66500

Source: IEA 2023

- *Net Zero Energy (NZE)* – is a concept that envisages a cost-effective and sustainable solution to the problem of energy independence and reduction of the carbon footprint, reduction of energy consumption and generation of the required amount of energy from renewable sources by 2050.

Both scenarios envisage a dramatic increase in energy employment (Fig. 6) and demand for a skilled workforce capable of implementing the goals and objectives set, as the number of new jobs in the clean energy sector will outweigh those lost in the fossil fuel sector. It is expected that by 2030, 14 million new jobs will be created in the clean energy sector and 16 million in related areas, while 9.5 million jobs will be lost in the fossil fuel sector (IEA, 2022).

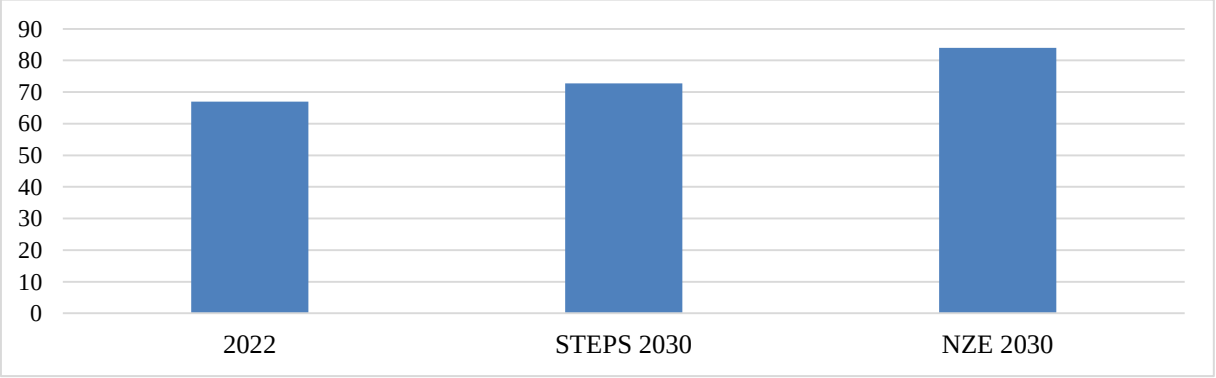

Fig. 6. Global energy employment by scenario, 2022-2030, [jobs in million]

Source: IEA 2023

Therefore, the global energy sector is facing challenges, on the one hand, of releasing labour from oil, gas and coal production and redistributing it to clean energy, and, on the other hand, of meeting the

growing demand for labour (Fig. 7) with specific high-tech skills (Table 2)

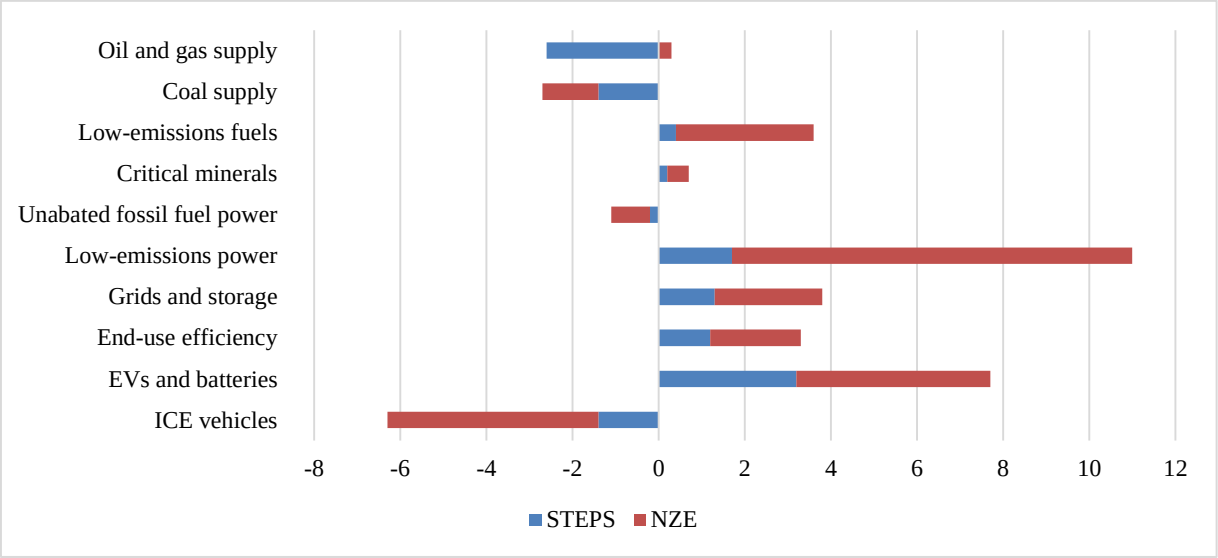

Fig. 7. Changes in global energy employment by sector and scenario, 2022-2030, [jobs in million]
Source: IEA 2023

Tab. 2

Examples of sector-specific occupations by energy technology

Solar	***Wind***
Photonics technicians	Atmospheric and space scientists
Solar energy systems engineers	Line installers and repairers
Solar PV installers	Wind energy engineers
Solar sales representatives and assessors	Wind energy operations managers
Solar thermal technicians	Solar thermal technicians
Nuclear	***Batteries***
Nuclear criticality safety engineers	Battery testers
Nuclear reactor operators	Battery maintainers (emergency storage)
Nuclear R&D technicians	Battery inspectors
Nuclear waste process operators	Battery repairers
Radiation protection technicians	Plant and system operators
Heating, ventilation, and air conditioning (HVAC)	***EVs***
HVAC engineers	Automotive service technicians and mechanics
Installers	Electronics engineers
Mechanics	Engine and other machine assemblers
Service sales representatives	Software developers
Sheet metal specialists	Team assemblers

Source: IEA 2023

Given that developing countries accounted for 74% of the increase in clean energy capacity in 2022 (Bloomberg 2024), the importance of the transnational factor of labour use is growing. In addition, amid global labour shortages and the ageing populations of developed countries, the energy transition underscores the need for TNCs to participate directly in workforce training and retraining.

Retraining of employees in the system of labour supply of the global energy industry.

In addition to the general problems of the global labour market, the international energy sector faces

specific issues related to the shortage of professional skills in the sectoral labour market and the need for inter-sectoral worker mobility. It is estimated that by 2030, the coal mining industry will lose 650,000 jobs (IEA, 2022), requiring a set of actions to minimise the economic and social consequences of the energy transition.

The limited supply of labour with the required qualifications (Fig. 8) generates high competition among employers for workers both within the energy industry as a whole and between individual energy sectors. Accordingly, many companies consider retraining employees as an effective way to ensure labour supply: more than half of the employees laid off due to the reduction of the fossil fuel sector can potentially be transferred to other energy sectors through retraining. Obviously, transnational companies have greater opportunities for retraining to preserve their labour potential, as geographical boundaries in labour supply do not constrain them and usually have a diversified structure.

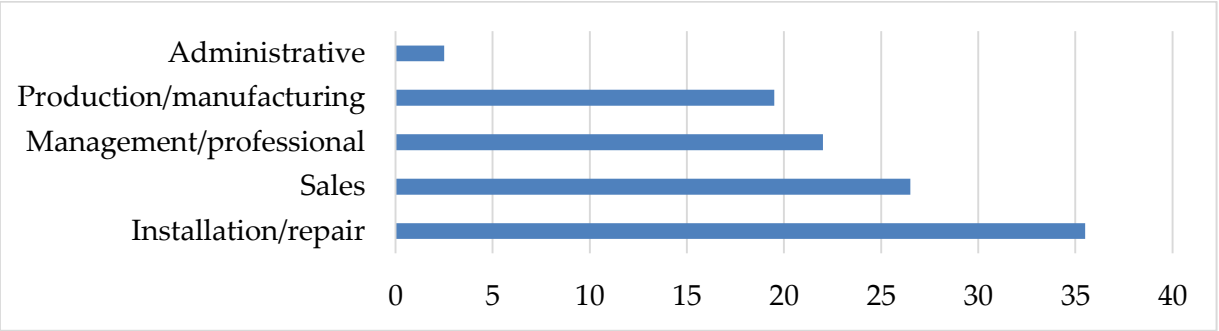

Fig. 8. Share of energy companies reporting perceived greater hiring difficulties than non-energy companies companies by occupation, 2023, [%]

Source: IEA 2023

The energy sector requires a more skilled workforce than other industries: 36% of employees have a university degree, 51% have relevant vocational training, and only 13% of those employed in the energy sector have low qualifications (Fig. 9). Against the background of the existing labor shortage, it is possible to meet the growing needs of the industry for a skilled workforce with appropriate professional specialization through requalification and retraining programs. This fits into the concept of job modernisation caused by the double transition and the introduction of a knowledge-based economic development model. Accordingly, it should be expected that the educational composition of the future labour force will shift toward a higher share of highly skilled workers and a lower share of low-skilled workers.

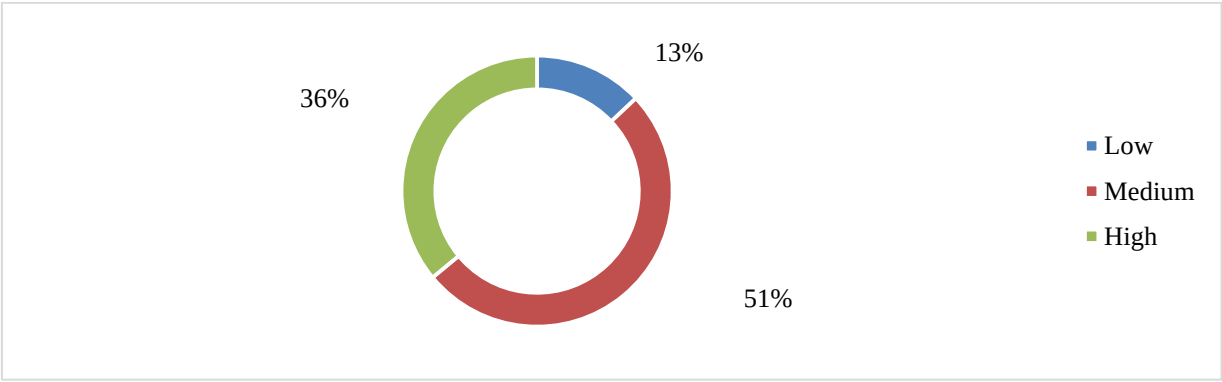

Fig. 9. Global energy employment by skill level, 2022, [%]

Source: IEA 2023

Most energy companies in different countries have developed their own retraining programs (Table 3), but this involves additional financial, time, and organisational costs. Accordingly, it is logical to provide institutional support for companies' efforts to develop qualification skills to meet the labour

needs of the energy sector, on the one hand, and to prevent the growth of structural unemployment due to mismatches between the skills available and those demanded by employers, on the other.

Tab. 3

Training course availability by clean energy technology in selected major economies, 2023

Course Training	***Argentina***	***Canada***	***Germany***	***Italy***	***South Korea***	***USA***	***Australia***	***China***	***India***	***Japan***	***Saudi Arabia***	***Turkey***	***Brazil***	***France***	***Indonesia***	***Mexico***	***South Africa***	***UK***
Wind	+	+	+	+	+	+	+			+		+	+	+	+		+	+
Solar photovoltaic	+	+	+	+	+	+	+	+	+	+	+	+	+	+	+	+	+	+
Ground-source heat pumps	*	+	+		+	+	+	+		+	*	+		+	+		*	+
Air-source heat pumps	*	+	+			+	+							+			+	+
Battery storage		+	+	*	+	+	+	*	+				+		+		+	+
Building retrofits	+	+		+	+	+	+		+				+	+			+	+

*+ - Available; * - Under development*

Source: IEA 2023

For example, in the EU, the *European Skills Agenda* (EC, 2024a) program provides for the retraining of 120 million workers annually in 2020-2025 to address the skills shortage, to facilitate the transition to green and digital technologies, accelerate innovation and increase competitiveness. The *Green Deal Industrial Plan* (EC, 2023b) is based on the production of zero-emission technologies. *Pact for Skills* (EC, 2023c) is based on retraining and professional development of employees in strategic EU industries through the creation of special programs, such as Net-Zero Industry Academies (EC, 2024b). In the EU, 2023 has been declared the *European Year of Skills* (EC, 2023a).

These approaches align with the EU's overall vision of the labour market, which includes growing demand for professionals in science, technology, engineering, mathematics (STEM) and IT. It is expected that by 2035, the demand for highly skilled labour will remain dominant in all sectors and professions in the EU (Cedefop, 2023).

The British *North Sea Transition Deal* (OGUK, 2021) provides for a set of actions to transfer personnel from the oil and gas industry to wind power and other clean energy sectors.

In the United States, the *Inflation Reduction Act* (IRA, 2022) was passed, introducing financial incentives for workforce training and retraining in clean energy.

In Scotland, the *Energy Skills Partnership* (ESP, 2021) acts as a link between education and industry, helping to adapt STEM fields to the needs of the energy transition.

In general, coordination between governments, educational institutions, and energy companies is crucial for institutional support of skills development. Examples of framework documents that promote this cooperation are the *Houston Energy Transition Initiative* (Houston, 2021) and the *EU Pact for Skills* (EC, 2023).

To facilitate the recognition of acquired skills, more than 165 countries have introduced National Qualification Frameworks to classify and recognise knowledge and competencies for specific industries

and professions, thereby increasing the efficiency of employee training and enabling targeted training and retraining programs to meet the needs of particular enterprises.

The general principles of a fair solution to the situation of employee redundancy are enshrined in the *Resolution concerning a just transition towards environmentally sustainable economies and societies for all*, adopted by the 11th International Labour Conference on June 30, 2023 (ILO, 2023).

Equally important, corporate training programs as part of energy transition efforts in many countries help improve young people's basic skills. For example, *India's Ministry of Skill Development and Entrepreneurship* is working to create a skills development ecosystem in which the development of the necessary qualifications for the energy sector is incorporated into vocational training (IEA, 2023).

As a result of the research, a Conceptual and structural model of the transnationalization of labour resource provision in the global energy sector can be proposed (Fig. 10), which reflects the systemic integration of labour resources worldwide, driven by global economic and technological changes.

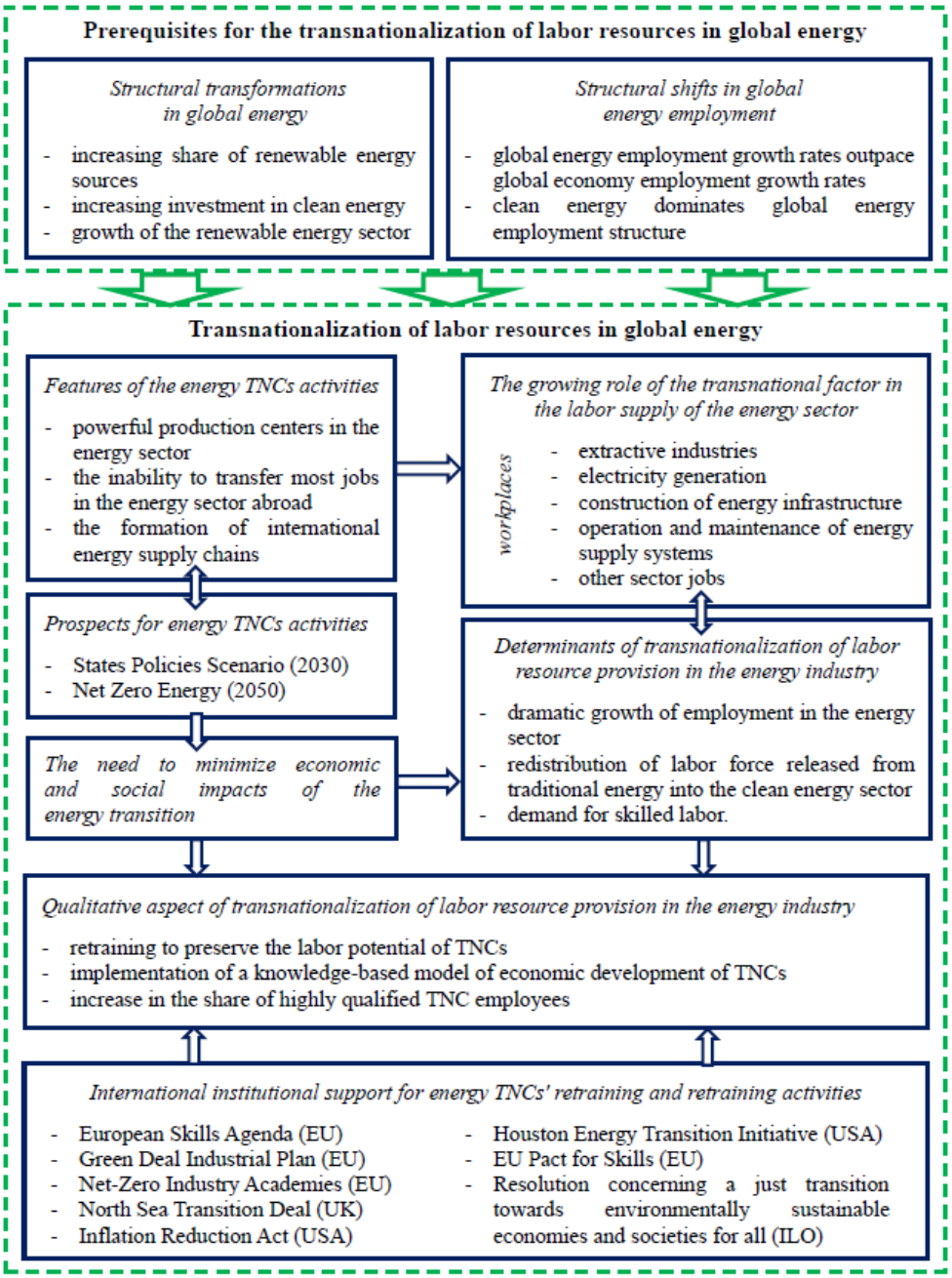

Fig. 10. Conceptual and structural model of the transnationalization of labour resource provision of global energy

Source: developed by the authors

Transnationalization is a necessary condition for the functioning of modern global energy, and managing this process requires consistency between countries' national economic policies and the needs of international business. In turn, structural transformations in the global energy sector associated with the transition to energy production from renewable sources require a comprehensive approach to providing the industry with labor, including the formation of the necessary qualifications of employees in accordance with the needs of renewable energy sectors, solving the problems of the released labor force from traditional energy sectors, retraining and advanced training, taking into account the transnational nature of the activities of energy companies.

4. CONCLUSIONS

The implementation of energy transition policies is increasingly intertwined with employment policies. Structural transformations in the energy sector, driven by the transition to renewable energy sources, directly affect the sector's employment structure.

The transnationalization of labour supply is extremely important for the development of the energy sector, given TNCs' role in international energy supply chains and their significant influence on the global labour landscape.

The clean energy labour supply and the solution to the problems of dismissed fossil fuel sector workers require a comprehensive approach at the international, national, and company levels to build a mechanism for developing the necessary skills for further employment of the dismissed labour force, and to provide appropriate institutional support at the national and international levels.

Author Contributions:

Each author contributed equally to all aspects of this research, including Conceptualization, Data curation, Formal analysis, Investigation, Methodology, Project administration, Supervision, Validation, Visualization, Writing – original draft, and Writing – review & editing

Acknowledgement: This research did not receive any outside support, including financial support.

Conflict of interest: The authors declare no conflict of interest.

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Received: July 12, 2025; **revised:** November 20, 2025; **accepted:** December 06, 2025; **published:** December 31, 2025.

Сіманавичене Жанета, Подунай Валерія, Калінін Владислав, Остропольський Олег. Структурні трансформації зайнятості у світовій енергетиці в контексті транснаціоналізації забезпечення трудовими ресурсами. *Журнал Прикарпатського університету імені Василя Стефаника*, **12** (4) (2025), 112-124.

Стаття присвячена структурним трансформаціям зайнятості у світовому енергетичному секторі в контексті транснаціоналізації пропозиції робочої сили. Досліджено глобальні тенденції структурних трансформацій зайнятості в енергетичному секторі. Встановлено, що завдяки сектору чистої енергетики темпи зростання зайнятості у світовому енергетичному секторі випередили темпи зростання загальної зайнятості у світі. Визначено, що в результаті масштабних інвестицій кількість зайнятих у чистій енергетиці перевищила кількість робочих місць, пов'язаних з викопним паливом. Підкреслено, що оскільки більшість робочих місць в енергетичному секторі неможливо перенести за кордон, роль транснаціонального фактора в розвитку енергетичного сектору зростає: ці сектори характеризуються міжнародним масштабом використання робочої сили та є ключовими джерелами зайнятості в кожному регіоні. Визначено, що перспективи розвитку енергетичних транснаціональних компаній визначаються світовими тенденціями розвитку енергетики, а тенденції кількості робочих місць критично залежать від темпів переходу до чистої енергетики. Зроблено висновок, що забезпечення робочою силою сектору чистої енергетики та вирішення проблем працівників сектору викопного палива вимагає комплексного підходу на міжнародному, національному та корпоративному рівнях з точки зору розвитку необхідних навичок та забезпечення відповідної інституційної підтримки.

Доведено, що перехід до зеленої енергетики тісно пов'язаний з політикою зайнятості, оскільки тягне за собою значні зміни в структурі робочих місць в енергетичному секторі. Це вимагає комплексного підходу на всіх рівнях для перепідготовки та подальшого працевлаштування вивільнених працівників, що працюють у сфері викопного палива. В результаті проведеного дослідження розроблено Концептуально-структурну модель транснаціоналізації трудоресурсного забезпечення глобальної енергетики, яка є системним відображенням процесу інтеграції трудових ресурсів у світовій енергетиці, керованого глобальними економічними та технологічними змінами.

Ключові слова: зайнятість у світовій енергетиці, сектор чистої енергії, енергетична незалежність, транснаціоналізація забезпечення трудовими ресурсами, глобальний ринок праці, екосистема розвитку навичок, професійний розвиток.