SOCIO-ECONOMIC IMPLICATIONS OF ENERGY TRANSITION: THE NEW ROLE OF HUMAN CAPITAL

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Abstract. Italy's energy landscape is undergoing a profound transformation, marked by expanding renewable capacity, fluctuating climatic conditions, and evolving market dynamics. In this context, human capital emerges as a critical driver of a just and effective energy transition. This paper investigates how skills, education, and workforce development shape Italy's path toward decarbonization, integrating a systematic review of the literature with empirical evidence on green employment and regional disparities. The analysis highlights that while Italy is advancing in renewable deployment and energy market integration, a persistent gap between labor supply and the skills demanded by emerging green sectors risks constraining progress. Significant territorial imbalances further amplify these challenges, revealing uneven capacities across regions to adapt and benefit from the transition. The findings highlight the need for integrated policies on education, reskilling, and labor inclusion to reinforce human capital and support a fair and sustainable energy transition.

1. Introduction

Recently, Italy's energy landscape exhibited notable shifts that reflect both the ongoing transition toward renewables and the system's responsiveness to varying climatic and market conditions. In March 2025, electricity available for consumption rose from a year earlier, driven mainly by a strong rebound in thermoelectric output and solid gains in solar generation. This expansion was tempered by pronounced declines in hydro and wind power, highlighting the sensitivity of weather-dependent sources to seasonal and climatic variability.

Over the same period, Italy markedly increased its power exports, signalling a stronger role in regional electricity markets and a more efficient use of cross-border interconnections (Terna, 2025). These dynamics underscore the complexity of Italy's energy transition, where increased solar capacity and thermal resilience coexist with fluctuating renewable yields, necessitating integrated strategies for stability and decarbonization. Specifically, current projections underscore the urgency of addressing human capital challenges.

A successful transition to renewable energy is driven not only by technological innovation and policy reforms but also by the critical contribution of workforce development and skill availability in supporting sustainable growth. While technological innovation and financial investment often dominate discussions, the role of human capital—the knowledge, skills, and expertise of the workforce—is increasingly recognized as a decisive factor in the success of this transition. The International Energy Agency (IEA) estimates that achieving net-zero emissions by 2050 will necessitate the creation of 14 million new energy-related jobs by 2030 (International Energy Agency, 2022). This includes positions ranging from highly technical roles, such as renewable energy engineers and grid specialists, to operational roles in project management and maintenance. At the same time, the phasing out of fossil fuels is expected to displace approximately 5 million jobs, resulting in a net gain of 9 million positions globally (Harvey, 2024). These shifts highlight the need for targeted workforce planning and training strategies to balance displacement with opportunities[1]. However, there is a growing concern about a significant mismatch between the skills available in the current labor market and those required for the energy transition. For instance, renewable energy sectors like solar power have already encountered difficulties in meeting labor demand[2] (Di Blanco, 2024). Such shortages risk delaying project timelines and increasing costs, thereby hindering progress toward global energy goals.

Against this backdrop, by integrating a systematic literature review with evidence on Italian green jobs and regional heterogeneity, we investigate the role of human capital in shaping Italy's energy-transition trajectory. Specifically, the paper addresses the following questions: (i) How is the demand for green jobs evolving across different sectors in Italy, and how do skill requirements and shortages influence this process? (ii) How is green employment distributed across Italian regions, and which territories are emerging as leaders or lagging behind in the green transition?

The Italian case is especially relevant given its ambitious climate goals, strong regional disparities, and the increasing role of firms in driving the energy transition.

Moreover, despite the growing body of literature on human capital and the green transition at the international level, there is a notable lack of studies specifically examining the Italian context. This gap limits our understanding of country-specific

[1] Recent macroeconomic modeling suggests that carbon revenues invested in green education significantly enhance long-term green human capital, reinforcing the need for strategic investment in education to support the low-carbon transition in Italy (Albanese, Busato, and Cisco, 2024).

[2] Reports indicate that while Italy had over 76,000 workers employed in the solar sector in 2023, there remains a significant gap in technical expertise, particularly among installers and technicians. To meet its target of 100,000 solar jobs by 2028, the country must address this skills shortage through targeted training initiatives

challenges and policy needs, particularly in terms of regional labor mismatches and skill development.

The paper is structured as follows: after reviewing the relevant literature on human capital and energy transition, we analyse the evolution of green jobs and regional disparities in Italy labor market tightness for green occupations. Finally, we discuss policy implications for education, training, and workforce planning and propose a framework for enabling a just and inclusive energy transition.

2. Literature review

Human capital plays a central role in improving energy production efficiency and reducing CO_2 emissions, thus serving as a critical enabler of the energy transition. It supports the development and adoption of clean technologies and pollution-free methods, reinforcing its strategic relevance in the shift from non-renewable to renewable energy sources.

A growing body of research investigates the interplay between human capital, technology, globalization, and CO_2 emissions. Kuzmin *et al.* (2023) highlight the contribution of green human capital to energy-technological development[3]. Ahmed *et al.* (2021), using cointegration analysis for Latin America and the Caribbean, show that human capital and ICT enhance globalization, promote economic growth, and reduce environmental degradation. Similarly, Yao *et al.* (2019) and Sart *et al.* (2024) confirm that human capital is a fundamental driver of sustainable energy transitions, fostering the diffusion of renewables and environmental awareness.

Further empirical evidence supports these findings. Esquivias *et al.* (2022), through panel data from 1990–2019, demonstrate that investment in human capital and renewable technologies improves energy efficiency and reduces CO_2 emissions. Hao *et al.* (2021), focusing on G7 countries, show that education-driven human capital boosts the adoption of eco-friendly technologies and carbon mitigation strategies. Zhang *et al.* (2022), studying OECD countries, find that human capital, technology, and energy pricing policies discourage fossil fuel use and support sustainable energy transitions. Mahmood *et al.* (2019) also include human capital in their analysis of Pakistan, showing that higher education levels promote cleaner production and reduced pollution. On a broader level, Sarkodie *et al.* (2020)

[3] In their study, Kuzmin *et al.* (2023) investigate the role of human capital investment in fostering sustainable socio-economic development within the energy sector. Employing a bibliometric methodology, the authors analyze a dataset of 1,933 documents indexed in the Web of Science database from 1991 to 2023. Their findings highlight a growing academic interest in this intersection, emphasizing that investments in human capital are perceived as vital for promoting innovation, accelerating the transition to renewable energy, and achieving long-term sustainability.

conceptualize the link between fossil fuel use, human capital, and climate mitigation in China, noting that renewable energy, income, and education reduce emissions and environmental degradation. Green Human Resource Management (GHRM) further enhances the contribution of human capital to sustainability. Amrutha and Geetha (2020), through a systematic review of 174 studies, demonstrate how GHRM supports environmental goals, corporate social responsibility, and employee well-being in the energy sector. Moreover, human capital influences energy transition not only through labour markets but also through individual consumption behavior. Households' adoption of renewable energy technologies is shaped by education, income, and age, directly impacting what energy is produced and consumed. Vainio *et al.* (2020) emphasize the need to integrate socio-psychological factors into energy transition analyses, while Veskioja *et al.* (2022) apply a multi-level perspective (MLP) to assess 85 European smart energy systems, underlining the importance of human-centered approaches in digital energy transitions.

3. Data Analysis

This section presents an empirical investigation of the Italian labor market in the context of the green transition. First, we investigate the evolution of green job demand across sectors, examining how skill requirements and shortages shape this transformation. This provides insight into which industries are driving employment growth and how effectively the labour market is adapting to the skills needed for the green transition. Second, we analyse the regional distribution of green employment and labour market tightness, identifying geographic disparities in skill availability. This perspective is crucial for informing region-specific policies that support reskilling, promote equitable access to green jobs, and prevent local gaps in the transition toward a sustainable economy.

3.1. Green skills and green job in Italy

The assessment of green skills in the labour market is limited by the absence of a common definition of green jobs and the lack of detailed data on the environmental content of specific occupations. A key international taxonomy is ONET[4] (Occupational Information Network) that offers a rare structured list of 204 "green" including "Increased Demand Occupations" (i.e. existing roles with rising demand,

[4] Developed by the U.S. Department of Labor, it provides one of the most comprehensive resources on occupations and skills, especially for green jobs.

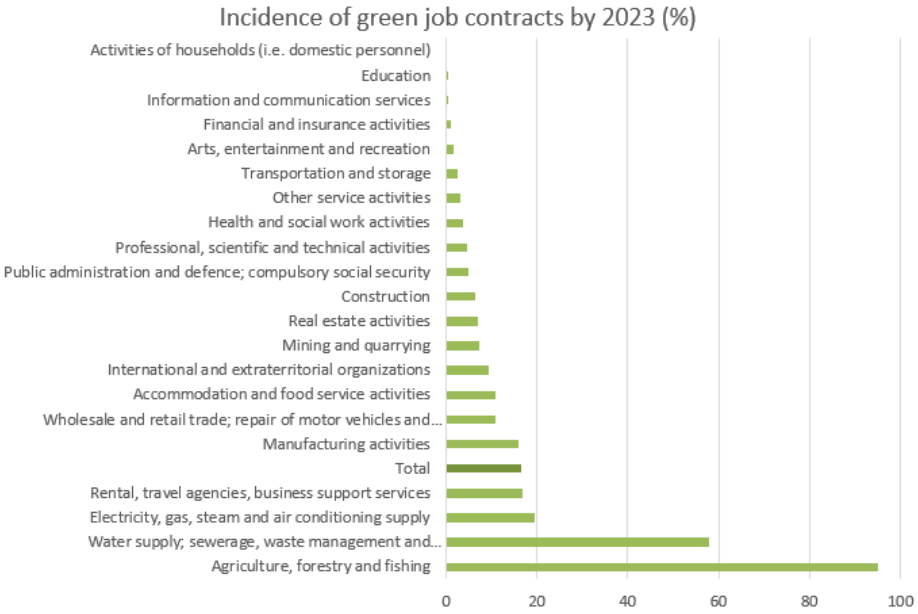
e.g., solar energy technicians), "Enhanced Skills Occupations" (i.e. traditional jobs requiring new environmental skills, e.g., mechanical engineers with green competencies), and "New and Emerging Occupations" (i.e. novel roles created by the green transition, e.g., carbon management specialists) (Sviluppo Lavoro Italia, 2024). In Italy, Unioncamere and Fondazione Symbola have operationalized this framework within the national production system, defining green jobs as work in agriculture, industry, and services that preserves or restores environmental quality and includes activities enhancing efficiency, quality, and eco-innovation (MASE). However, despite these definitional and taxonomic advances, measurement practices too often default to traditional binary classifications that distinguish between "green" and "non green jobs," which often overlook the hybrid nature of many roles, particularly in sectors like construction and manufacturing (Consoli *et al.*, 2016). To overcome these limitations, recent studies have increasingly adopted a task-based approach, offering a more continuous and nuanced measure of occupational "greenness" (Autor, 2013; Vona *et al.*, 2018). Within this approach, the framework maps emerging green tasks in renewables and energy efficiency (Bradley *et al.*, 2025) and, crucially, detects skill mismatches and training gaps that can inform inclusive labour policies for a just transition (Brunetti *et al.*, 2025).

Overall, in the past decade, the demand for green jobs has followed a complex trajectory, characterized more by the gradual integration of environmental competencies into traditional occupations than by a clear shift toward highly specialized roles. Nevertheless, a persistent skills gap threatens to slow this progress, highlighting the need for targeted reskilling and upskilling. In Italy, data from the Comunicazioni Obbligatorie show no notable rise in demand for high-skilled green professionals: most new contracts are low- or medium-skill, with advanced technical roles concentrated in a few sectors while employment growth largely reflects conventional jobs that are incrementally adding environmental competencies. Specifically, the share of contracts classified as green jobs has fluctuated, moving from 19.7% in 2014 to 16.5% in 2023, with a temporary peak of 22.2% in 2020[5] (Sviluppo lavoro Italia, 2024). At the same time, green-investing firms are markedly more active in developing their workforce—prioritizing upskilling, reskilling, and targeted training in areas like risk management, transversal, and managerial skills—positioning themselves ahead in sustainable innovation and adaptation (Fondazione Symbola – Unioncamere, 2024).

[5] The Labour Market Intelligence (LMI) dashboard developed by Sviluppo Lavoro Italia integrates diverse data sources to provide territorial insights on labour demand, skills needs, and the green and digital orientation of over 600 professions. This tool is critical for aligning training systems with emerging labour market dynamics and informing effective policy responses to both ecological and technological transitions (Sviluppo Lavoro Italia, 2024a).

In terms of sectoral distribution, as illustrated in the following figure, green employment is highly concentrated in a few key industries. The agriculture, forestry, and fishing sector shows a particularly high incidence, accounting for 95.1% of contracts—equivalent to 1,357,724 new hires. This is followed by water supply, sewerage, waste management, and remediation activities, which represent 57.8% of green job contracts (30,405 in total), and by the electricity, gas, steam, and air conditioning supply sector, with an incidence of 19.5% (2,089 contracts). Other sectors with a notable presence of green employment include rental, travel agencies, business support services (16.9%, 143,560 contracts) and manufacturing activities (15.9%, 148,198 contracts) (Sviluppo Lavoro Italia, 2024).

Figure 1 – *Sectoral distribution of green employment.*



Source: Authors' computations from Sviluppo Lavoro Italia (2024), Table 4.3.A.

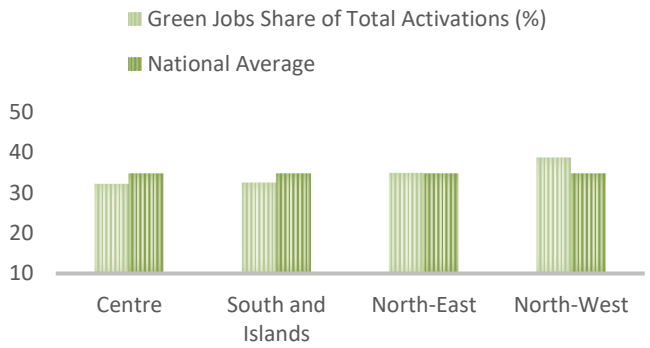
This distribution indicates that the green transition has advanced most rapidly in resource- and energy-intensive industries, and is progressively diffusing into services and manufacturing as firms embed sustainability within core operations. Hovewer, the comparatively limited presence of advanced technical and managerial profiles points to a latent skills gap that constrains the transition's transformative potential.

Within this framework, human capital is pivotal. Firms that invest strategically in upskilling and reskilling exhibit greater adaptability and innovative capacity, acting as catalysts that diffuse sustainability practices across value chains. Accordingly, the Fondo Nuove Competenze has emerged as a key instrument in Italy, co-financing firm-level training to support ecological and digital transitions and helping align workforce capabilities with evolving operational needs (Ministero del Lavoro e delle Politiche Sociali, 2024). Overall, the evidence suggests that Italy's green transition will depend more on the quality of workers' skills than on how many green jobs are created.

3.2. Regional disparities

Regional disparities remain a defining feature of Italy's green transition, revealing uneven progress in green job creation, skill availability, and overall labour market dynamics. Evidence from the Green Italy 2024 Report by Fondazione Symbola and Unioncamere confirms that, in 2023, significant territorial imbalances persisted in the distribution of green job activations across the country. The Centre recorded the strongest year-over-year acceleration (+12.6%), suggesting efforts to close the gap with other areas, but it still lagged in absolute levels. The North-West remained the leading area by volume and by the share of green jobs in new contracts (38.7%, above the 34.8% national average), followed by the North-East (34.9%); the South and Islands occupied an intermediate position (32.5%), with the Centre slightly lower (32.2%). Overall, regional differences reduced only marginally, pointing to uneven progress in the diffusion of green employment (Fondazione Symbola–Unioncamere, 2024).

Figure 3 – *Green Employment Intensity by Italian Region (% of Total Activations).*

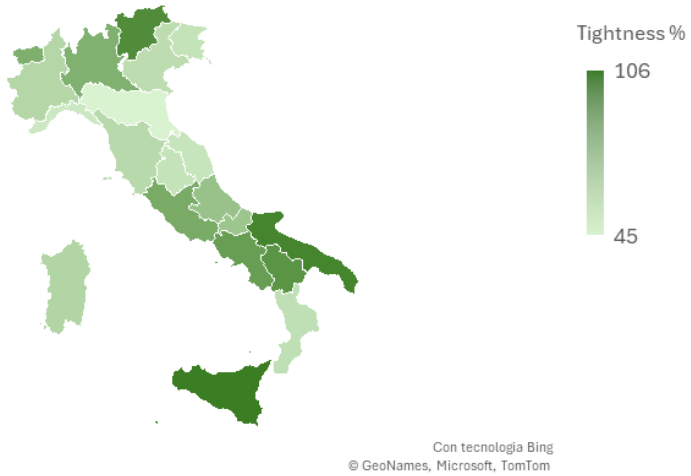


Source: Our own elaboration from Fondazione Symbola – Unioncamere, 2024.

These patterns suggest that Italy's green transition is still regionally unbalanced: gains concentrate where industrial capabilities, innovation assets, and environmental supply chains are already dense, while lagging areas grow slightly faster mainly because the gap is narrowing (i.e. not because their structures are converging). These dynamics point to the need for regionally differentiated strategies that strengthen local innovation ecosystems and workforce capabilities. Without targeted measures to support the Centre and South, the transition may entrench existing territorial disparities and slow the spread of sustainable employment nationwide.

A complementary perspective on territorial imbalances comes from labour-market tightness, which captures the percentage gap between the tightness of green jobs and that of the average job (OECD, 2023)[6]. This indicator highlights that Southern regions post the highest values—Sicily (+106.4%), Apulia (+102.1%), Campania (+89.4%)—signalling acute shortages of green skills; notably, Bolzano and Trento are also above +90%, showing that fast-growing, advanced markets can be equally constrained by skills. By contrast, Emilia-Romagna (+45.3%), Liguria (+50.2%), and Marche (+52.3%) display comparatively lower tightness, consistent with a closer supply–demand alignment (or a slower pace of green-job openings).

Figure 4 – *Occupational Tightness in Green Jobs by Italian Region.*



Source: Our own elaboration of data from OECD (2023).

[6] The indicator draws on data from the OECD (2023) report *Job Creation and Local Economic Development 2023: Bridging the Great Green Divide*. It measures, for each regional labour market, the percentage difference between the tightness of green jobs and that of the average job. Labour market tightness is defined as the ratio of vacancies to employment, while green jobs are identified as occupations in which at least 10% of tasks are "green," following the OECD's task-based framework.

Overall, the evidence implies that regional disparities reflect not only different employment levels but also heterogeneous matching capacity—hence the need for place-sensitive policies that expand training channels and work-based learning in lagging areas, while scaling advanced, time-to-skill programs in leading regions. Taken together, the evidence from green job creation and labour market tightness highlights that Italy's green transition is advancing at an uneven pace, shaped by both structural and capacity-related differences across regions. Some territories combine strong industrial and innovation assets with growing skill shortages, while others show weaker demand but relatively better alignment between available and required competencies. These dynamics underscore the importance of regionally differentiated strategies that simultaneously strengthen human capital, stimulate green investment, and ensure fair access to quality employment.

4. Conclusions

This paper underscores the pivotal role of human capital in shaping Italy's energy transition, showing that the evolution of green job demand across sectors, together with effective skill development and the reduction of regional disparities, is fundamental to achieving a sustainable and balanced transformation. The analysis provides three main insights. First, the green transition has advanced most rapidly in resource- and energy-intensive industries, gradually extending to services and manufacturing as sustainability becomes embedded in core business operations. Second, a persistent shortage of advanced technical and managerial profiles reveals a structural skills gap that constrains the transformative potential of green growth. Third, significant territorial asymmetries in both job creation and skill matching highlight the need for regionally differentiated strategies to ensure an equitable diffusion of green employment opportunities. To address these challenges, it is essential to adopt a multi-faceted approach to human capital development. First, it would be appropriate to align education systems with emerging industry needs as the transition spreads beyond resource- and energy-intensive sectors. Specifically, it would be useful embed sustainability in formation programs, expand work-integrated learning (apprenticeships, internships) with local firms, and update occupational standards to include green competencies in services and manufacturing. Second, to face the shortage of advanced technical and managerial roles, it appears relevant to implement targeted reskilling/upskilling, namely fast-track programmes and micro-credentials in renewables, grid modernisation, systems integration, and sustainability management, among many others. Third, policymakers might address territorial asymmetries through place-sensitive measures, including developing

regional training hubs tied to local specialisations, harmonising qualifications, and recognising prior learning to ease mobility.

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