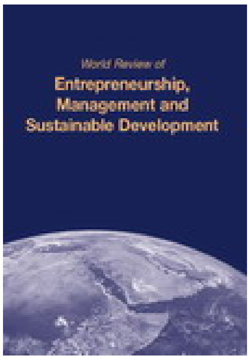

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From coal to green: skills pathways for key emerging sectors in just transition regions

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From coal to green: skills pathways for key emerging sectors in just transition regions

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Abstract: The European Green Deal and Just Transition Mechanism present workforce adaptation challenges in regions transitioning from fossil fuel industries. While research documents green skills shortages, sector-specific evidence from Just Transition contexts remains limited. This study examines skills gaps and intervention priorities across Energy, Construction and ICT in Greek Just Transition regions. Drawing on survey data from 519 enterprises, we employ Kruskal-Wallis H-tests, Skills Gap Index analysis and a priority classification framework. Results suggest substantial sectoral differentiation: seven high-priority competencies were identified, six in Energy and one in Construction, with none in ICT. Energy exhibits the largest gaps (mean SGI = 0.162), Construction a focused deficit in green building practices, and ICT smaller gaps but the lowest green transition awareness. Cross-sector analysis indicates 91.4% of competencies are sector-specific, challenging generic training. The study proposes a transition-intensity framework linking sectoral transformation to skills-gap severity and a three-tier priority framework for workforce development.

Keywords: green skills; just transition; skills gap; workforce development.

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1 Introduction

Green transition workforce policy rests on a largely untested assumption: that 'green skills' constitute a coherent category amenable to uniform training interventions. Yet within a single coal-dependent region, the energy sector demands workers who can structure green financing for hydrogen projects, the construction sector needs tradespeople certified in nearly-zero-energy building techniques, and the ICT sector requires developers capable of deploying smart grid management platforms. These competencies share a policy label but little else. If sector-specific skill requirements diverge as sharply as practitioners suspect, then the allocation logic underpinning current green workforce programmes, which typically pool training budgets across sectors, may systematically misdirect resources.

This study investigates whether such divergence exists, how large it is, and what it implies for resource allocation. We examine three key emerging sectors (Energy, Construction, ICT) within Greek Just Transition regions, where an accelerated 2028 lignite phase-out deadline (Ziouzios et al., 2021) compresses workforce adaptation timelines beyond what most European coal regions experience. Greece's Western

Macedonia, with lignite activities accounting for approximately 34% of regional Gross Value Added, exemplifies the tension between national-level green skills projections and the operational reality of place-based, sector-specific work-force transformation (European Commission, 2020). The green transition in former lignite regions represents a multi-level challenge spanning individual workforce capabilities, firm-level adaptation, and national policy frameworks (Dana and Salamzadeh, 2024), necessitating granular evidence on sector-differentiated competency needs.

The potential for skills mismatches between declining and emerging sectors is compounded by labour market dynamics that limit worker mobility. Evidence from industrial transitions elsewhere suggests that displaced workers often face substantial barriers to relocation, particularly when employment is concentrated in communities with deep occupational identities and multi-generational employment patterns (Vona, 2021). Greece's lignite regions exemplify this dynamic: Western Macedonia has hosted coal mining operations for over half a century, creating workforce characteristics and community ties that constrain both the feasibility and desirability of worker transitions to new sectors or distant locations. The region's geographic isolation, separated from major urban centres by mountainous terrain, further limits access to alternative employment markets and training infrastructure.

Yet evidence on successful workforce transitions in energy communities remains limited. Studies of coal phase-outs in other European contexts suggest that workers displaced from fossil fuel industries often struggle to secure comparable employment, with outcomes varying considerably based on local economic conditions, available retraining programs, and the presence of growing sectors that can absorb displaced workers (Gambhir et al., 2024). Fewer than 1% of fossil fuel workers transition to green jobs in fossil-dependent regions, with even lower rates for older workers and those without tertiary education (Curtis et al., 2023). These challenges underscore the importance of developing detailed, sector-specific information that can guide workforce development investments toward competencies with demonstrable employer demand in affected regions (ILO, 2019; Cedefop, 2021).

This study examines how skills requirements and gaps differ across three key emerging sectors (Energy, Construction, and ICT) within Greek Just Transition regions. Drawing on employer survey data from 519 enterprises, we employ non-parametric statistical methods and a priority classification framework combining gap magnitude with skill importance. The analysis focuses on employer perceptions rather than worker self-assessments, capturing the demand-side perspective that shapes hiring decisions and workforce planning.

Our analysis yields three main findings. First, skills gaps differ significantly across sectors: Energy exhibits the largest gaps (mean Skills Gap Index = 0.162) with six high-priority competencies requiring immediate intervention, while ICT demonstrates the smallest gaps (mean SGI = 0.101) despite reporting the lowest awareness of green transition relevance. Second, cross-sector analysis indicates that 91.4% of unique competencies are sector-specific, a finding that challenges generic training approaches and suggests limited skills transferability across transition sectors. Third, we observe an inverse relationship between employer perceptions of green impact and measured skills gap magnitude: Construction reports the highest green transition awareness but moderate gaps, while Energy shows moderate awareness alongside the largest gaps.

This study adds to recent research examining green skills requirements in European contexts. Where prior work has documented aggregate green skills shortages at national levels, we provide sector-specific skills gap profiles from Just Transition regions facing accelerated transition timelines. Methodologically, we develop a priority classification framework that policy actors can apply to assess intervention needs within their own regions. Practically, the three-tier priority framework presented in Section 5 offers guidance for allocating training resources across sectors experiencing differentiated transformation intensities. Taken together, these contributions are organised around four guiding questions: (1) What priority skills do employers require in each sector? (2) What skills gaps exist, and how do gap magnitudes compare across sectors? (3) How do sectors perceive their contribution to green transition? (4) What priorities should guide workforce development investment?

2 Literature review

2.1 Sectoral approaches to green skills

A central tension runs through the green skills literature: national-level workforce forecasts consistently identify aggregate shortages, yet the operational reality of coal phase-out unfolds at the regional and sectoral level, where aggregate projections offer limited guidance. Vona et al. (2018) demonstrate through task-based analysis that green skills requirements vary substantially across industries, with engineering and technical competencies dominating in energy-intensive sectors while construction requires fundamentally different skill profiles. This sectoral heterogeneity is well established at the national level (OECD, 2023; Keese and Marcolin, 2023), but its implications for regions undergoing accelerated Just Transition remain poorly understood. National forecasts assume gradual sectoral rebalancing; coal-dependent regions face abrupt structural change, where the mismatch between existing workforce endowments and emerging sectoral demands is far more acute.

The European Commission (2024a) recognises distinct decarbonisation pathways for energy, buildings, and transport sectors through the Fit for 55 package, yet the accompanying workforce planning instruments (the Pact for Skills, sectoral blueprints) operate at aggregate EU or national levels, leaving regional implementers without the sector-specific skills evidence needed to design targeted interventions (Cedefop, 2023). Recent systematic reviews confirm that green entrepreneurship research has predominantly generalised across sectors, with limited attention to the specialised green competences required in specific industries (Singh et al., 2025). This gap is particularly acute in coal-dependent regions, where the nature and urgency of competency needs differ substantially from those captured in national-level assessments.

Fuchs (2024) argues that green skills definitions depend heavily on sectoral context and normative assumptions about what constitutes sustainability within different industries. The disconnect between national forecasts and regional realities is further compounded by the diversity of emerging sectors within a single transition region: the energy sector confronts direct technological disruption, construction faces regulatory-driven transformation, and ICT operates as a cross-cutting enabler. Each demands distinct competency profiles, yet regional policymakers typically receive only aggregate ‘green skills’ projections that obscure these sectoral differences (OECD, 2023; Cedefop, 2023).

The Just Transition framework adds a spatial dimension to this sectoral challenge. Coal regions require fundamentally different interventions than urban service economies, and the challenges facing displaced workers vary substantially depending on both their previous occupational skills and the emerging sectors in their regions (European Commission, 2024a). The European Commission identifies 35 coal regions across Europe requiring tailored support, emphasising that place-based and sector-based strategies must complement each other (IEA, 2023; IRENA & ILO, 2024). Yet the empirical evidence base for sector-specific skills planning within these regions remains thin: most assessments aggregate across sectors or across regions, but rarely examine the intersection of both.

2.2 Theoretical frameworks: skills and green transition

The relationship between skills and green transition operates through multiple mechanisms. Vona et al. (2019) propose a task-based approach distinguishing green jobs by occupational content rather than industry. Human capital theory (Schultz, 1961; Becker, 1964) suggests that workers with appropriate skills facilitate clean technology adoption and reduce implementation barriers (Keese and Marcolin, 2023). The skills-transition nexus operates bidirectionally: green policies stimulate demand for competencies, while skill availability enables more ambitious environmental targets (Vona et al., 2018). Recent evidence from Industry 5.0 contexts indicates that analytical and technology competencies are the primary drivers of employability, while traditionally valued soft skills show limited impact (Mohan et al., 2025), underscoring the need for sector-specific rather than generic skills assessment frameworks.

Green skills versus enabling digital skills. A conceptual distinction is necessary between two categories of competencies that the literature often conflates. *Green skills* are competencies directly required for environmentally sustainable activities, including renewable energy system design, energy efficiency assessment, and circular economy practices. *Enabling digital skills* are competencies that facilitate green outcomes indirectly through technology application, such as data analytics, building information modelling (BIM), and smart grid management. This distinction matters analytically because it generates different expectations about skills gap patterns. Sectors undergoing direct green transformation (Energy) should exhibit gaps primarily in green skills, while the ICT sector's contribution operates through the enabling channel: its workers need not possess deep environmental expertise but must be capable of applying digital tools to sustainability challenges. The 'twin transition' concept (Cedefop, 2023; ETF, 2024) links green and digital transformations, but risks obscuring this asymmetry by treating all technology-related competencies as equivalent regardless of their functional role. Digital technology has been characterised as a 'levelling tool' enabling resource-constrained enterprises to overcome structural barriers (Dana and Salamzadeh, 2024), yet in Just Transition regions this equalising potential remains contingent on the availability of adequate sector-specific digital competencies among the local workforce.

Transition pathway theory emphasises skill transferability for orderly transitions. The IEA (2023) identifies substantial transferability among fossil fuel workers. The fourth industrial revolution further complicates this picture by demanding that professionals develop integrated competency profiles spanning technical, managerial, and interpersonal domains (Olaya-Escobar et al., 2024), a pattern that may vary systematically across sectors with different transformation intensities.

2.3 Green skills in key emerging sectors

2.3.1 Energy sector

The energy sector experiences rapid employment growth alongside persistent skill shortages. IRENA reports 16.2 million global renewable energy jobs in 2023 (IRENA & ILO, 2024), while 75% of employers struggle to hire for essential roles (IEA, 2024). Technical requirements span renewable system design, hydrogen technologies, and energy efficiency assessment. Approximately half of fossil fuel workers possess transferable skills, though coal miners face greater retraining challenges (IEA, 2023).

2.3.2 Construction sector

Construction accounts for 36% of global energy consumption and 39% of CO_2 emissions (Chen et al., 2020). The EU Renovation Wave targets 35 million building improvements by 2030, requiring massive workforce upskilling. Priority competencies include energy efficiency assessment, digital tools (BIM, CAD), and sustainable building practices (BUILD UP, 2024). LinkedIn reports construction has the second-highest green talent demand (LinkedIn, 2023).

2.3.3 ICT sector

ICT occupies a conceptually distinct position in the green transition: rather than undergoing direct decarbonisation, it functions as an enabling sector whose digital tools (smart grids, building management systems, data analytics) support emissions reduction across other industries (ETF, 2024). ICT itself accounts for 8–10% of EU energy consumption (Cedefop, 2024), creating a dual mandate: reducing its own environmental footprint while developing the digital infrastructure that other sectors require for their green transitions. ICT workers with green credentials are hired at 29% higher rates (LinkedIn, 2023). This enabling role means that ICT skills gaps, even when smaller in magnitude than those in directly transitioning sectors, may have disproportionate downstream effects on the pace of green transition across the broader economy.

2.4 Skills gaps in transitioning regions

Coal and lignite regions face particularly acute skill challenges during green transition. The European Commission (2024a) reports 208,000 jobs in EU coal mines and power plants as of 2021, with production declining 12% in 2024 alone. These regions require targeted interventions addressing both immediate displacement and longer-term economic restructuring (Gambhir et al., 2024).

Research on skill mismatches in transitioning economies identifies substantial barriers to worker reallocation. Green jobs typically require higher educational attainment than traditional industrial occupations, creating education gaps that disproportionately affect older workers with limited formal education (Vona, 2021). Methodological approaches to skills gap identification and closure have been developed across various sectoral contexts (Chhibber and Paposa, 2024), yet few have been applied specifically to green transition sectors, where the nature and urgency of competency needs differ substantially from conventional labour markets. Importantly, few studies provide the sector-specific analysis needed to guide targeted interventions; most assessments focus on aggregate national shortages rather than differentiated requirements across key transition sectors within affected regions.

2.5 Conceptual framework and research propositions

Our conceptual framework synthesises insights from human capital theory, task-based approaches to green employment, and transition pathway research. The framework posits that sectoral transformation intensity, ranging from direct transition (Energy) through indirect transition (Construction) to enabling transition (ICT), systematically shapes both skills gap magnitude and the composition of priority competencies. This relationship operates through the mechanism of technological discontinuity: sectors experiencing more fundamental technological change require workforce capabilities that diverge more substantially from existing skill endowments. The expected ordering is therefore: Direct Transition (Energy) > Indirect Transition (Construction) > Enabling Transition (ICT), with outcomes manifesting as sector-specific skills profiles and differentiated intervention priorities.

Based on the literature reviewed and the conceptual framework, we advance four research propositions, each linked to a measurable empirical pattern and a falsifiability condition:

P1 (Sectoral Differentiation): Skills gap magnitudes are expected to differ significantly across sectors, reflecting distinct transition intensities. *Empirical test:* The Kruskal-Wallis H-test applied to sector-level SGI distributions should yield $p < 0.05$ with a meaningful effect size ($\eta^2 \geq 0.06$). P1 would be refuted if sectoral SGI distributions are statistically indistinguishable.

P2 (Transition Intensity): Energy (direct transition) should exhibit larger gaps than Construction (indirect) and ICT (enabling). *Empirical test:* The mean SGI ordering should follow Energy > Construction > ICT, confirmed by significant pairwise Dunn's tests. P2 would be refuted if the ordering is reversed or if Energy does not exhibit the largest mean SGI; for instance, if ICT gaps exceeded Energy gaps, this would challenge the assumption that direct transition sectors face the most acute skills deficits.

P3 (Skills Specificity): The majority of required competencies are expected to be sector-specific rather than transferable. *Empirical test:* The proportion of high-priority skills appearing in only one sector should exceed 50%. P3 would be refuted if the majority of high-priority competencies were shared across two or more sectors, suggesting a common green skills core rather than sector-differentiated profiles.

P4 (Perception-Gap Disconnect): Employer perceptions of green impact may not align with measured skills gaps. *Empirical test:* The sector with the highest perceived green transition contribution should not be the sector with the largest SGI. P4 would be refuted if perceived green impact and measured skills gaps were positively correlated across sectors, that is, if sectors perceiving greater green relevance also exhibited proportionally larger skills deficits.

3 Methodology

3.1 Research design

This study employs a quantitative cross-sectional research design. The analysis focuses on three key emerging sectors demonstrating strategic importance for green transition.

The research targets Just Transition regions of Greece, enabling systematic comparison across sectors and regions.

The study encompasses three geographic clusters designated as Just Transition areas. Western Macedonia constitutes the primary lignite-dependent region of Greece, historically concentrating coal mining and power generation employment. Megalopolis in the Peloponnese represents the second major lignite zone, hosting the Megalopolis power plant complex. The Island Regions, comprising Crete, North Aegean, and South Aegean peripheries, require energy transition toward renewable sources due to their reliance on imported fossil fuels and high potential for solar and wind energy development.

Primary data derive from a structured employer survey, while secondary data provide contextual economic indicators. This approach aligns with established green skills methodologies (Vona et al., 2018; OECD, 2023).

3.2 Key emerging sectors

Three sectors were selected based on their centrality to the European Union's twin transition framework. The European Green Digital Coalition identifies energy and construction/buildings among six priority sectors requiring coordinated green and digital transformation (European Green Digital Coalition, 2024). The Joint Research Centre emphasises that 'the most evident and profound transformations' in the twin transition occur in the energy and construction sectors (Joint Research Centre, 2022). ICT was included as an enabling sector, recognised for its role in facilitating both green and digital transitions across the economy (European Commission, 2024b). Agriculture and tourism, while important for regional development in Just Transition areas, were excluded from this analysis as they represent distinct transformation pathways warranting separate investigation.

Table 1 Sector selection criteria

Sector	*Growth potential*	*Green relevance*
Energy	3.54	3.52
Construction	3.95	3.94
ICT	3.90	2.89

Notes: Growth Potential = Mean employer rating of sectoral development prospects (1–5 scale). Green Relevance

= Mean employer rating of positive impact from energy transition (1–5 scale). N = 519 enterprises (Energy: 140, Construction: 229, ICT: 150).

3.3 Data collection

Primary data were collected through a structured online survey conducted between August and September 2025 within a publicly funded Just Transition research project. The target population comprised all active enterprises operating in ten economic sectors within the Just Transition regions, as recorded in the General Commercial Registry (G.E.MI.). Sampling employed a stratified approach based on sector and region, with enterprise contact lists drawn from business registries and sectoral associations. Respondents included business owners, managers, and HR professionals with direct knowledge of workforce requirements and capabilities.

Survey instrument construction. The questionnaire assessed sector-specific competencies drawn from the European Skills, Competences, Qualifications and Occupations (ESCO) taxonomy, a standardised EU classification developed by the European Commission (DG Employment, Social Affairs and Inclusion) in coordination with Cedefop through extensive stakeholder consultation, including sectoral reference groups comprising labour market and vocational training experts across member states (European Commission, 2017). Skills were mapped to each sector using NACE-to-ESCO crosswalks, which link occupations to sector-level skill profiles, ensuring systematic and reproducible competency selection grounded in an institutionally validated framework rather than ad hoc researcher judgement. The final instrument comprised 89 sector-specific competencies across the three key sectors (Energy: 39, Construction: 23, ICT: 27), reflecting each sector's distinct occupational profile as defined by the ESCO taxonomy. Two methodological limitations warrant acknowledgment: employer-reported proficiency ratings may be subject to social desirability bias, particularly for competencies perceived as normatively important (e.g., environmental awareness), and anchoring effects cannot be fully excluded when the same respondent rates both necessity and current levels sequentially. These potential biases operate in opposite directions: social desirability may inflate required levels while anchoring may compress gaps. These biases are partially mitigated by the dual-assessment design, which provides internal consistency checks across the assessed items. Survey distribution employed a mixed methodology: electronic distribution via personalised links through a web-based survey platform, telephone follow-up, and in-person contact where feasible. A total of 1,961 enterprises responded across the target regions. Response rates varied by region: Western Macedonia exhibited the highest response rate (50.2%; 516 of 1,029 contacted), followed by Peloponnese (23.5%; 829 of 3,531), and Island Regions (1.8%; 616 of 34,260). The lower response rate in Island Regions reflects the larger denominator (enterprises across Crete, North Aegean, and South Aegean) rather than lower absolute participation.

The geographic distribution of the final sample comprises Peloponnese (42%), Island Regions (32%), and Western Macedonia (26%).

Sector assignment followed NACE Rev. 2 classification codes as reported in business registry records. Occupational and skill classifications follow the ESCO taxonomy for standardised European comparability.

Non-response bias assessment. The overall response rate of 5.05% (1,961 of 38,820 contacted enterprises) is comparable to large-scale employer surveys in similar contexts: the European Company Survey reports response rates of 5–12% across Southern European economies (Eurofound, 2019), and enterprise surveys in Greek peripheral regions typically achieve 3–8% (OECD, 2021). Response rates varied substantially by region: Western Macedonia, where the project had the strongest institutional partnerships, exhibited the highest rate (50.2%), while Island Regions recorded 1.8%. The Island Regions figure reflects a denominator effect: the sampling frame encompassed all registered enterprises across Crete, North Aegean, and South Aegean (N = 34,260), the majority of which operate in sectors outside the study scope (tourism, retail), yet absolute participation (616 enterprises) exceeded that of Western Macedonia (516). To assess whether regional response variation affects substantive conclusions, we conducted a sensitivity analysis restricting the sample to Western Macedonia and Peloponnese (the two higher-response regions). Sectoral SGI rankings remain unchanged under this restriction: Energy exhibits the largest gaps (mean SGI = 0.129), followed by Construction (0.102), then ICT (0.073). The Kruskal-Wallis H-statistic retains significance ($H = 10.96$, $p = 0.004$), and the effect size remains meaningful ($\eta^2 = 0.065$). Following Armstrong and Overton (1977), wave analysis compared early versus late respondents on key outcome variables, under the assumption that late respondents more closely resemble non-respondents. Results indicate minimal systematic bias for skills-related constructs: two of three regional comparisons on skills satisfaction showed no significant early-late differences ($p > 0.05$), with only Peloponnese exhibiting a marginally significant difference ($p = .038$, effect size = 0.21 points on 5-point scale). Furthermore, comparison with official ELSTAT employment data indicates that sectors underrepresented in the sample (notably Agriculture at 6.4% sample vs. 17.9% population) exhibit larger skills gaps than over-represented sectors (ICT, Construction). Any compositional bias therefore operates in a conservative direction: adjusted estimates would increase rather than decrease reported gaps (Groves, 2006). Collectively, the benchmark comparison, wave analysis, and regional sensitivity check suggest that non-response bias does not materially affect the reported sectoral patterns, though we acknowledge that respondent enterprises may be systematically more engaged with workforce development than non-respondents.

For each identified skill, employers provided two distinct assessments. First, skill necessity ratings capture the importance of each competency for effective job performance, measured on a 1–5 Likert scale. Second, current proficiency assessments reflect employer judgments of workforce capability levels, also measured on a 1–5 Likert scale. Importantly, both assessments are employer-reported rather than objectively measured, reflecting employer perceptions of workforce capabilities. This approach captures demand-side perspectives but may differ from worker self-assessments or independently verified competency levels. The difference between these two measures provides the foundation for Skills Gap Index calculation.

3.4 Analysis

3.4.1 Skills gap index

The Skills Gap Index (SGI) operationalises disparity between required and possessed competencies (OECD, 2021; Vona et al., 2018):

$$SGI = 1 - \frac{Current\ Level}{Required\ Level} \tag{1}$$

The intuition behind the ratio formulation is straightforward: a 1-point gap matters more for a critical skill (Required = 5) than for a peripheral one (Required = 3). The ratio captures this by expressing the deficit relative to the skill's importance. The ratio-based formulation was selected over simple difference for three reasons. First, it normalises gap magnitude relative to skill importance: a gap of 1 point on a highly-required skill (Required = 5) represents a smaller relative deficit than the same absolute gap on a less critical skill (Required = 3). Second, the formulation produces a bounded 0–1 scale facilitating cross-sector comparison. Third, ratio-based approaches align with established skills gap methodologies in the literature (OECD, 2021).

Likert scale and interval assumption. The SGI formula treats ordinal Likert ratings as interval-level data, an assumption common in applied skills research but not without risk (Carifio and Perla, 2008). If the psychological distance between adjacent scale points is unequal (e.g., the step from 3 to 4 is subjectively larger than from 4 to 5), ratios may distort gap magnitudes. We address this concern through three complementary safeguards rather than assuming the limitation away. However, ratio-based measures applied to Likert-scale data carry known limitations: they assume interval-level properties and may produce distorted rankings when denominator values are low. Three safeguards address these concerns. First, the Priority Matrix (Section 3.2.3) serves as a robustness mechanism by jointly considering SGI magnitude *and* absolute importance thresholds (Required ≥ 3.8). Skills are classified as High Priority only when both conditions hold, filtering potential distortions from low-denominator ratios: a skill with Required = 2.0 cannot qualify as High Priority regardless of its SGI, since low-denominator distortions primarily affect skills employers consider less essential. Second, across all 89 skills assessed in the three sectors, no Required rating fell below 2.69, limiting the practical range of denominator-related distortion. Third, when simple differences (Required − Current) are used instead of ratios, sectoral rankings remain unchanged: Energy exhibits the largest absolute gaps, followed by Construction and ICT. The Priority Matrix classification also remains stable under simple differences, with Energy accounting for the majority of high-priority skills across both formulations. Additionally, sensitivity analysis confirmed that the main findings are robust to alternative threshold specifications (Table 12, Appendix B). Using SGI ≥ 0.18 (more inclusive) identifies 9 high-priority skills versus 7 at the baseline threshold, with Energy still accounting for the majority (7/9). Using SGI ≥ 0.22 (more restrictive) identifies 6 high-priority skills, with Energy accounting for 5 and Construction for 1. Sectoral rankings remain unchanged across all specifications: Energy exhibits the largest gaps, followed by Construction, then ICT. Similarly, adjusting the importance threshold to Required ≥ 3.7 or ≥ 4.0 does not alter the substantive conclusions regarding sectoral differentiation or the concentration of intervention priorities in the Energy sector.

Table 2 Robustness check: SGI ratio vs. simple difference

	Energy	*Construction*	*ICT*
SGI Ratio (baseline)	0.162	0.144	0.101
Simple Difference (Req − Cur)	0.58	0.57	0.39
Ranking	1st	2nd	3rd

Notes: SGI Ratio = 1 − (Current/Required). Simple Difference = Required − Current. Sectoral rankings are identical under both operationalisations. Kruskal-Wallis tests indicate significant cross-sector differences for both measures ($p < .001$).

Values between 0.10–0.19 represent moderate gaps, while values ≥ 0.20 indicate substantial gaps requiring intervention.

3.4.2 Analytical approach

The analysis employs the Kruskal-Wallis H-test to examine whether skills gap distributions differ significantly across sectors (Kruskal and Wallis, 1952). This non-parametric test was selected due to ordinal Likert-scale measurements and significant departures from normality. Post-hoc pairwise comparisons employ Dunn's test with Bonferroni correction (Dunn, 1964). Effect sizes are quantified using eta-squared (η^2), interpreted following Cohen (1988): small (0.01– 0.05), medium (0.06–0.13), large (≥ 0.14).

Unit of analysis. The SGI analysis operates at the skill-region level rather than the firm level. Each observation represents the mean gap for a specific competency within a given sector, aggregated across all responding firms in that sector. This yields $N = 185$ skill-region observations (89 competencies × 3 regions, minus competencies assessed in fewer than 5 firms per region). The transition from firm-level responses to skill-level aggregates is necessary because the research questions concern sectoral skills profiles rather than individual firm characteristics. However, this aggregation raises two concerns regarding statistical independence.

First, multiple skill-level observations from the same sector share a common respondent pool, introducing within-sector correlation. Second, skills within the same competency domain (e.g., digital skills) may co-vary systematically. We acknowledge that the Kruskal-Wallis test assumes independent observations and does not account for this nested structure. Two alternative approaches could address this limitation: clustered standard errors at the sector level, or a hierarchical (multilevel) model with skills nested within sectors. Both approaches were considered but not implemented for two reasons: the small number of clusters ($k = 3$ sectors) renders cluster-robust inference unreliable (Cameron and Miller, 2015), and the hierarchical model requires more clusters than grouping variables for stable variance component estimation. Instead, we rely on the consistency of results across multiple robustness specifications (ratio vs. difference SGI, varying thresholds) as indirect evidence that the sectoral patterns are not artefacts of the analytical structure.

3.4.3 Priority matrix construction

A Priority Matrix integrates two dimensions: Skills Gap Severity (SGI ≥ 0.20) and Skill Importance (Required ≥ 3.8, corresponding to sample mean). The intersection yields four quadrants: High Priority (high gap, high importance), Watch (high gap, lower importance), Maintain (low gap, high importance), and Low Priority (low gap, lower importance).

3.5 Validity

The research design incorporates multiple validity safeguards. *Construct validity* is enhanced through ESCO standardised classifications, enabling comparability across European contexts.

External validity is strengthened by representation across all three Just Transition study regions.

Internal consistency is ensured through the dual-assessment approach, whereby employers provide both necessity and proficiency ratings for each skill, enabling consistent gap measurement across competency domains.

4 Findings

This section presents empirical findings from the employer survey conducted across Greek Just Transition regions ($N = 1{,}961$ enterprises, with 519 in the three key emerging sectors). Three headline results frame the detailed analysis that follows. First, skills gap magnitudes differ significantly across sectors ($H = 19.07$, $p < 0.001$, $\eta^2 = 0.094$), with mean SGI values following a gradient consistent with transition intensity: Energy (0.162) > Construction (0.144) > ICT (0.101). Second, the Priority Matrix identifies seven high-priority competencies requiring immediate intervention, six concentrated in Energy and one in Construction, with zero in ICT. Third, employer perceptions of green transition relevance do not align with measured skills gaps: Construction rates its green impact highest ($M = 3.94$) despite exhibiting only one high-priority deficit, while Energy reports moderate green awareness ($M = 3.52$) despite the most severe skills shortfalls ($\eta^2 = 0.133$ for green impact perceptions). The analysis proceeds from sectoral profiles (Section 4.1) through sector-specific skills gap analysis (Section 4.2), cross-sector transferability (Section 4.3), priority classification (Section 4.4), green transition contribution (Section 4.5), and future skills demand (Section 4.6).

4.1 Overview of key sectors

Table 3 Sectoral profile of key emerging sectors

Sector	*N*	*Emp. 2023*	*Emp. 2025*	*Growth*	*Green*	*Prospects*
Energy	140	1,743	2,246	+28.9%	3.52	3.54
Construction	229	1,044	1,225	+17.3%	3.94	3.95
ICT	150	698	1,132	+62.2%	2.89	3.90
Total	**519**	**3,485**	**4,603**	**+32.1%**	–	–

Note: *N* = number of enterprises. Emp. = Employment (total employees). Growth = percentage change 2023– 2025. Green = Green Impact rating. Prospects = Growth Prospects rating. All ratings on 1–5 Likert scale.

Table 3 and Figure 5 (Appendix) reveal substantial variation in growth expectations and green impact perceptions across sectors. ICT demonstrates the highest growth expectations (+62.2%) despite the smallest current workforce, suggesting emerging sector dynamism. Construction exhibits the highest green impact perception ($M = 3.94$) and growth prospects ($M = 3.95$), which may reflect the sector's direct engagement with EU Renovation Wave objectives. Energy, despite its central transition role, reports more moderate perceptions across both dimensions. This pattern may reflect realistic assessment of transformational challenges ahead, though it could also indicate sector-specific calibration of expectations. These findings suggest that employer perceptions of sectoral relevance develop through sector-specific mechanisms rather than objective transition intensity.

Next, we examine cross-sectoral differences in skills gaps and employer perceptions. Table 14 (Appendix) presents detailed statistical results. We find that Skills Gap Index differs significantly across sectors ($H = 19.07$, $p < 0.001$, $\eta^2 = 0.094$), with Energy exhibiting the highest gaps and ICT the lowest. Green impact perceptions also differ significantly ($H = 49.40$, $p < 0.001$, $\eta^2 = 0.133$), with Construction employers perceiving the strongest positive effects from energy transition.

These results are consistent with **P1** (sectoral differentiation in skills gaps). The medium effect size ($\eta^2 = 0.094$) indicates that sectoral affiliation explains approximately 9.4% of variance in skills gap magnitude. The omnibus tests also indicate significant differences in employer perceptions across sectors, with Green Impact exhibiting the largest effect size ($\eta^2 = 0.133$), a finding we explore further in relation to P4.

4.2 Sectoral green skills analysis

4.2.1 Energy sector

The Energy sector exhibits the most pronounced skills gaps among the three sectors analysed, with a mean Skills Gap Index (SGI) of 0.162 across 39 assessed competencies. Table 8 (Appendix A) presents detailed skills gap data.

Notably, the largest gaps concentrate not in core technical competencies but in financial and strategic domains (green financing, SGI = 0.331) alongside emerging renewable technologies (hydrogen, wind, energy storage). This pattern suggests that the Energy sector's transformation challenge extends beyond technical workforce capabilities to encompass financial literacy and investment expertise required for capital-intensive renewable projects.

Alternative interpretation. The prominence of financial and strategic competencies at the top of Energy's gap profile warrants cautious interpretation. Two mechanisms other than genuine capability deficits could produce this pattern. First, *measurement salience*: green financing and strategic planning are highly visible in current policy discourse (EU Green Deal, Just Transition Fund), and employers may anchor 'required' ratings on salient policy language rather than operational job demands, inflating gaps for policy-adjacent competencies. Second, *domain-specific calibration*: Energy employers with deep technical backgrounds may rate technical skills generously (compressing technical gaps) while rating unfamiliar financial competencies more harshly. To assess whether the pattern reflects true sectoral need rather than measurement artefact, we examined regional consistency. The green financing gap appears across all three study regions (Peloponnese: SGI = 0.163; Western Macedonia: SGI = 0.191; Island Regions: SGI = 0.483, $n = 35$ enterprises), suggesting that the finding is not driven by a single regional outlier, though the substantially larger gap in Island Regions warrants further investigation. Nevertheless, employer-reported assessments cannot fully distinguish perceived importance from operational necessity, and the financial gap finding should be validated through complementary methods (e.g., worker self-assessment, job task analysis).

The policy implication is that Energy sector training programs should integrate financial and strategic components alongside technical curricula.

4.2.2 Construction sector

The Construction sector exhibits a mean SGI of 0.144 across 23 competencies, positioning it between Energy (highest gaps) and ICT (lowest gaps). Table 9 (Appendix A) presents detailed skills gap data.

Unlike Energy, Construction exhibits a single dominant deficit (green skills, SGI = 0.238) substantially exceeding all other gaps, which cluster below 0.18. This concentrated profile suggests that Construction's transition challenge is more focused than Energy's multi-dimensional requirements. Green skills also carry the highest employer importance rating (Required = 4.40), indicating strong demand-side recognition of sustainability competencies for EU Renovation Wave implementation. On the other hand, this concentrated pattern may reflect Construction employers anchoring their assessments on salient policy discourse (green building), potentially underreporting gaps in less visible competency areas. The policy implication is that Construction sector interventions may prioritise targeted green skills certification rather than the comprehensive transformation required in Energy.

4.2.3 ICT sector

The ICT sector exhibits the lowest mean SGI (0.101) across 27 competencies, suggesting relatively better alignment between workforce capabilities and employer requirements. Table 10 (Appendix A) presents detailed skills gap data.

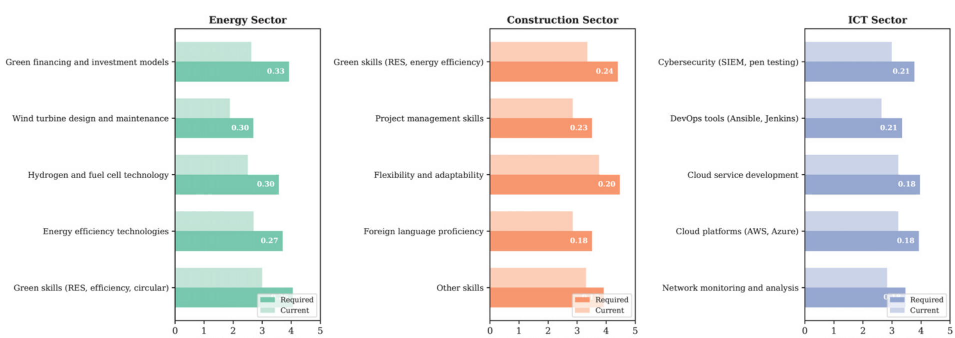
ICT's gap profile is exclusively technical-digital: DevOps, cybersecurity, and cloud competencies dominate, with no sustainability-specific skills appearing among top deficits. This absence is notable given that ICT employers also report the lowest green transition awareness ($M = 2.89$). This finding is examined further in the Discussion.

4.2.4 Sectoral comparison summary

Table 4 Sectoral skills gap summary

Metric	*Energy*	*Construction*	*ICT*
Total skills assessed	39	23	27
Mean required level	3.51	4.00	3.88
Mean current level	2.93	3.43	3.49
Mean SGI	0.162	0.144	0.101
Largest gap	0.331	0.238	0.211
Primary gap area	Green financing	Green skills	DevOps/Cloud

Figure 1 Skills gap index by sector and region (see online version for colours)



Note: Heatmap displays mean SGI values across three Just Transition regions. Darker shading indicates larger skills gaps. SGI calculated as 1 − (Current/Required).

Regional analysis indicates notable geographic variation in skills gap severity. As shown in Figure 1, the Island regions exhibit the largest gaps across all sectors, with Energy showing particularly acute deficits (SGI = 0.27), the highest value observed in the entire matrix. In contrast, Western Macedonia, despite being the primary lignite-dependent region, exhibits the lowest gaps across all sectors (Energy: 0.10, Construction: 0.03, ICT: 0.01). The Peloponnese occupies an intermediate position, with Construction showing the highest regional gap (SGI = 0.18).

Several interpretations may explain these patterns. The Island pattern may reflect transition toward renewable energy sources (solar, wind) without commensurate workforce preparation, compounded by geographic isolation limiting access to specialised training. Western Macedonia's low gaps present a counterintuitive finding given its lignite dependency, raising interpretive questions regarding possible policy success, compositional effects, and self-selection bias, which are explored in the Discussion.

These findings are consistent with **P2** (transition intensity): Energy (direct transition) exhibits the highest gaps (mean SGI = 0.162), followed by Construction (indirect transition, SGI = 0.144), and ICT (enabling transition, SGI = 0.101). The observed ordering, with direct transition sectors exhibiting larger gaps than enabling sectors, is consistent with theoretical frameworks positing that technological discontinuity magnitude shapes workforce adaptation requirements (Vona et al., 2018). Energy's transformation from fossil fuels to renewables represents fundamental technological substitution, while ICT's contribution operates through optimisation of existing digital capabilities. This gradient suggests that sectors undergoing more radical transformation may require proportionally greater training investment to achieve comparable workforce readiness.

4.3 Cross-sector skills analysis

Analysis of 81 unique skills across the three sectors indicates remarkably limited overlap (see Table 15 in Appendix). We find that only one skill (foreign language proficiency) appears across all three sectors. These findings are consistent with **P3** (skills specificity): 91.4% of unique competencies are sector-specific, challenging generic 'green skills' approaches.

Distinguishing genuine specificity from survey artefact. Because the survey instrument employed sector-specific ESCO-based skill lists tailored to each sector's occupational profile, the 91.4% specificity figure requires careful interpretation. Three categories of explanation are possible. First, *genuine sector-bound skills*: competencies such as hydrogen technology operation (Energy), building energy performance certification (Construction), and DevOps pipeline management (ICT) are inherently sector-specific by occupational definition; no survey design could make them transferable. Based on occupational classification of the 81 unique competencies, approximately 63% fall into this category, representing technical skills tied to sector-specific equipment, regulations, or workflows. Second, *potentially transferable skills classified as sector-specific*: competencies such as project management, strategic planning, and quality assurance appear in only one sector's assessment list despite having potential cross-sector applicability. This reflects ESCO's occupation-based taxonomy, which assigns general competencies to specific occupational profiles. Approximately 27% of unique skills fall into this category. Third, *transversal skills included across sectors*: the survey explicitly included crosscutting competencies (foreign languages, digital literacy, communication) in all three sectoral assessments; these constitute the 8.6% overlap observed. The second category, potentially transferable skills appearing in only one list, represents the portion of the 91.4% figure most susceptible to survey design artefact. Even if all such skills were reclassified as transferable, the genuine specificity rate would remain above 63%, still indicating that the majority of green transition competencies are sector-bound. We therefore interpret the 91.4% figure as an upper bound on specificity, with approximately 63% representing a conservative lower bound based on occupational classification of the assessed competencies.

The policy implications of this skills specificity finding may be substantial. Generic 'green skills' training programs, while potentially valuable for awareness-raising, may not substitute for sector-tailored curricula addressing the distinct competency requirements identified in Tables 8–10 (Appendix A). Energy workers require financial and technological competencies (green financing, hydrogen systems) absent from Construction and ICT profiles. Construction workers need regulatory and materials knowledge (building codes, energy efficiency) that appear irrelevant to other sectors. ICT specialists require digital infrastructure expertise (DevOps, cloud platforms) with limited transferability to physical-asset sectors. This pattern is consistent with human capital theory's emphasis on occupation-specific skills (Becker, 1964) and task-based approaches distinguishing green employment by occupational content (Vona et al., 2019).

4.4 Skills gap priority analysis

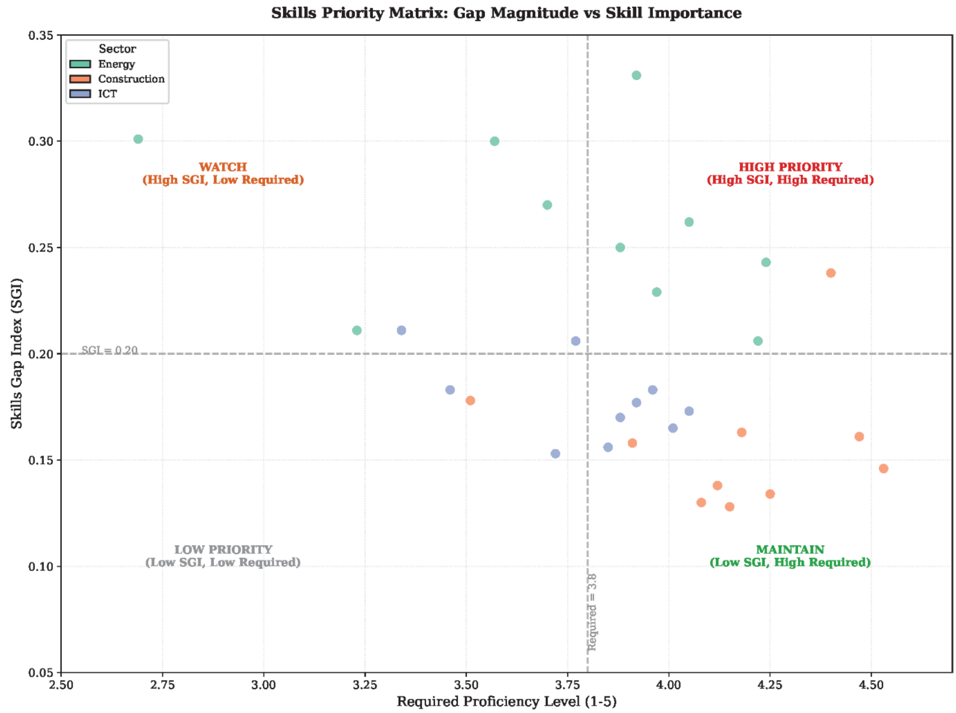
Table 5 Skills priority classification by sector

Priority category	*Energy*	*Construction*	*ICT*
High Priority	6	1	0
Watch	4	0	2
Maintain	0	8	6
Low Priority	0	1	2
Total Assessed	**10**	**10**	**10**

Notes: Classification based on top 10 skills gaps per sector (skills ranked below the top 10 exhibit lower SGI values by construction and therefore cannot meet the High Priority threshold). High Priority: SGI $\geq$ 0.20 AND Required $\geq$ 3.8. Seven high-priority competencies were identified across sectors: six in Energy and one in Construction.

Seven high-priority competencies were identified across the three sectors: six in Energy and one in Construction (Table 5). We observe a striking sectoral asymmetry in intervention urgency: Energy concentrates 86% (6/7) of all high-priority skills, while ICT exhibits zero high-priority gaps. ICT's largest deficit (DevOps tools, SGI = 0.211) exceeds the gap threshold but falls below the importance threshold (Required = 3.34 < 3.8), indicating that employers view these as specialised rather than universally critical competencies. This pattern appears to reflect fundamental differences in sectoral transformation dynamics. Energy requires simultaneous development of novel technical competencies (renewable technologies, storage systems) and strategic capabilities (green financing, decision-making) to execute capital-intensive infrastructure projects, whereas ICT's existing technical workforce already meets importance thresholds, requiring only incremental upskilling. On the other hand, employer importance ratings may reflect sectoral maturity rather than objective skill criticality: Energy employers, navigating an unfamiliar transition, may overstate importance relative to ICT employers accustomed to continuous technological change. The policy implication is that resource allocation for workforce development may prioritise Energy sector interventions, where the concentration of high-priority gaps suggests systemic rather than marginal deficits.

Figure 2 Skills priority matrix: gap magnitude by skill importance (see online version for colours)



Notes: Skills in the upper-right quadrant (High Priority) exhibit both substantial gaps (SGI ≥ 0.20) and high employer-rated importance (Required ≥ 3.8). Seven high-priority competencies were identified: six in Energy and one in Construction. High-priority skills: (1) Energy: Green financing (Req: 3.92); (2) Energy: Green skills RES (Req: 4.05); (3) Energy: Energy storage (Req: 3.88); (4) Energy: Decision-making (Req: 4.24); (5) Energy: Strategic thinking (Req: 3.97); (6) Energy: Problem-solving (Req: 4.22); (7) Construction: Green skills (Req: 4.40).

4.5 Contribution to green transition

Table 6 Green transition contribution metrics by sector

Metric	*Energy*	*Construction*	*ICT*
N (enterprises)	140	229	150
Green Impact (M)	3.52	3.94	2.89
Growth Prospects (M)	3.54	3.95	3.90
Employment Growth (%)	+28.9	+17.3	+62.2
Green Skills SGI	0.262	0.238	–
High Priority Skills	6	1	0

The pattern revealed by Figure 6 (Appendix) is consistent with a perception-gap disconnect (P4): Construction perceives the highest green impact (M = 3.94) despite exhibiting only one high-priority skill gap, while Energy perceives moderate impact (M = 3.52) despite having six high-priority gaps. This pattern suggests that employer awareness of sectoral green relevance may develop through different mechanisms than workforce capability assessment.

Construction's high green awareness likely reflects the sector's direct engagement with building renovation and energy efficiency, which represent visible and tangible activities aligned with sustainability discourse. Energy's more moderate self-assessment, despite facing the most severe skills deficits, may indicate realistic acknowledgment of transformational challenges ahead.

On the other hand, Construction employers, operating in a competitive market for green contracts, may strategically overstate green orientation; conversely, Energy employers may anchor comparisons to fully decarbonised operations not yet achieved. The policy implication is that green transition awareness may not reliably signal workforce readiness, and skills assessment programs may benefit from supplementing employer perceptions with objective competency measurement.

4.6 Future skills demand

Table 7 Future skills demand and enterprise adaptation readiness

Metric	*Energy*	*Construction*	*ICT*
N (enterprises)	140	229	150
Employment 2023	1,743	1,044	698
Employment 2024	2,111	1,110	930
Employment 2025 (est.)	2,246	1,225	1,132
Growth 2023–2025 (%)	+28.9	+17.3	+62.2
Investment readiness	3.33	3.90	3.13
Innovation readiness	3.35	3.89	3.15
New activities	3.36	3.68	3.13
Internationalisation	3.31	3.74	3.04
Overall readiness	**3.34**	**3.80**	**3.11**

Turning to employment trajectories and workforce absorption capacity (see also Figure 7 in Appendix), ICT's projected growth (+62.2%) far exceeds Energy (+28.9%) and Construction (+17.3%), suggesting substantial capacity to absorb transitioning workers from declining industries. However, this absorption potential must be interpreted alongside the readiness scores, which indicate a striking paradox: ICT exhibits the lowest overall adaptation readiness (M = 3.11) despite the highest growth trajectory. This pattern may reflect capacity constraints (rapid growth straining existing organisational capabilities) or structural factors whereby smaller, agile ICT firms grow faster but report lower readiness than larger, established Construction enterprises (M = 3.80). On the other hand, readiness self-assessment may correlate with sector maturity rather than objective capacity: Construction's longer institutional history may generate familiarity with adaptation discourse that inflates reported readiness. The policy implication is that employment growth projections may not be conflated with seamless workforce absorption; ICT's growth potential may require complementary investments in enterprise development capacity alongside worker training programs.

5 Discussion

5.1 Proposition verification summary

Our empirical analysis is broadly consistent with all four research propositions advanced in Section 2. P1 (sectoral differentiation) finds support in the Kruskal-Wallis test on SGI ($H = 19.07$, $p < 0.001$, $\eta^2 = 0.094$), indicating that skills gap magnitudes differ significantly across sectors. P2 (transition intensity) finds support in the observed ordering of mean SGI values: Energy (0.162) exceeds Construction (0.144), which in turn exceeds ICT (0.101), consistent with the hierarchy predicted by the transition intensity framework. P3 (skills specificity) finds support in the finding that 91.4% of unique competencies are sector-specific, challenging generic approaches to green skills development. P4 (perception-gap disconnect) finds support in the inverse relationship between employer perceptions of green impact and actual skills gap magnitude, suggesting that awareness of transition relevance may develop through different mechanisms than workforce capability.

The ICT sector's paradoxically low green awareness ($M = 2.89$) despite its highest employment growth (+62.2%) warrants particular attention. This finding is consistent with the 'twin transition' literature (Cedefop, 2023; Joint Research Centre, 2022), which positions ICT firms as enablers rather than direct participants in the green transition. ICT employers may not perceive their activities as 'green' because their contribution operates indirectly, through smart grids, building management systems, and energy optimisation platforms, rather than through direct emissions reduction. On the other hand, alternative explanations merit consideration. First, a *measurement artefact* may operate: the survey instrument's framing of 'green transition' likely invoked narrow conceptions emphasising physical environmental activities (renewable energy, building retrofits) over digital enablement, potentially underestimating ICT's perceived relevance. Second, *sectoral identity* effects may lead ICT employers to self-identify primarily as technology providers rather than sustainability actors, regardless of their actual environmental contribution. Third, *business model heterogeneity* within the ICT sector may explain the low mean: while some firms develop sustainability-oriented solutions (smart grids, carbon tracking platforms), others focus on applications with no environmental orientation (gaming, social media, e-commerce), diluting the sectoral average. Fourth, the *geographic concentration* of surveyed ICT firms in Just Transition regions, historically coal-dependent areas with less developed digital ecosystems, may not represent the broader Greek ICT sector's green orientation. This interpretation uncertainty suggests that policy interventions for ICT may focus on awareness-raising and strategic reorientation toward sustainability applications rather than technical upskilling.

This finding carries broader implications for understanding the role of enabling sectors in the twin transition. The JRC (2022) identifies five major greenhouse gas-emitting sectors requiring transformation (energy, buildings, transport, agriculture, and energy-intensive industries), positioning ICT not among these direct emitters but rather as enabling infrastructure that facilitates decarbonisation across all other sectors. Our empirical observation of low green self-perception among ICT employers, despite demonstrated workforce readiness and high growth trajectories, may reflect this structural position within the transition architecture. Enabling sectors contribute to sustainability outcomes indirectly, through the technologies and platforms they develop for deployment in other sectors, rather than through visible emissions reductions attributable to their own operations. If this interpretation holds, conventional metrics of green transition awareness may systematically underestimate the contribution of enabling sectors, with implications for how policymakers evaluate sectoral engagement with sustainability objectives and allocate workforce development resources.

5.2 Theoretical implications

The findings contribute to theoretical understanding of green skills dynamics in three ways. First, the observed sectoral gradient in skills gaps (Energy > Construction > ICT) is consistent with transition intensity frameworks positing that technological discontinuity magnitude determines workforce adaptation requirements (Vona et al., 2018). Sectors undergoing fundamental technological substitution appear to exhibit larger gaps than those optimising existing capabilities. The green entrepreneurship literature has identified the absence of sector-specific evidence on green competences as a key research frontier (Singh et al., 2025); our empirical gradient directly addresses this gap by demonstrating that green skills requirements are not uniform across sectors but follow predictable patterns linked to transformation intensity. Second, the 91.4% skills specificity finding challenges universal 'green skills' constructs, and is consistent with task-based approaches emphasising occupational content over industry classification (Vona et al., 2019; Consoli et al., 2016). The categorisation of workforce requirements into technical, managerial, and interpersonal domains (Olaya-Escobar et al., 2024) provides a complementary lens: each sector in our analysis requires a distinct combination of these competency types, with Energy demanding primarily technical-financial skills, Construction emphasising regulatory-practical competencies, and ICT requiring digital-analytical capabilities. Third, the inverse relationship between green perception and skills gaps suggests that employer awareness may develop through sector-specific mechanisms distinct from workforce capability assessment, a finding with potential implications for how policymakers interpret employer self-reports. This disconnect parallels evidence from the digitalisation literature, where enterprises' strong digital orientation did not translate into superior performance outcomes (Kotiranta et al., 2024), suggesting a broader pattern in which sector-level optimism about transformation may coexist with unaddressed competency deficits.

5.3 Interpretation of regional patterns

The regional findings reported in Section 4.2.4 require careful interpretation. Western Macedonia's unexpectedly low skills gaps across all sectors, despite being Greece's primary lignite-dependent region facing substantial workforce displacement, may reflect several mechanisms. On the one hand, concentrated Just Transition policy attention, including EU-funded training programs and targeted interventions as Greece's flagship decarbonisation zone, may have successfully addressed workforce deficits ahead of other regions. However, as Greece's Just Transition Fund programme was only adopted in June 2022 (European Commission, 2022), most training interventions remain in early implementation phases, and formal outcome evaluations have not yet been published. On the other hand, this interpretation must be weighed against plausible alternatives. Compositional effects may explain the pattern if enterprises experiencing severe skills mismatches have already closed or relocated, leaving a sample dominated by survivors with adequate workforce capabilities. Self-selection bias may operate if employers facing critical skills shortages were less likely to participate in voluntary surveys. Response calibration differences may emerge if respondents in high-scrutiny policy zones rate their workforces more favourably due to social desirability or familiarity with evaluation frameworks. Disentangling these mechanisms requires longitudinal data tracking enterprise dynamics and workforce development outcomes over time, a limitation of the present cross-sectional design. Despite this interpretive uncertainty, the policy relevance remains: whether Western Macedonia's low gaps reflect successful intervention or methodological artefacts, the region's workforce position appears more favourable than that of Island regions, which may inform regional resource allocation priorities.

5.4 Policy implications

5.4.1 National policy: sectoral priority tiers

Based on the priority analysis, a three-tier national framework for sectoral skills investment emerges as appropriate for the Greek Just Transition context. This framework synthesises skills gap severity, adaptation readiness, and transition relevance into differentiated intervention strategies. The economic imperative driving green competency demand is reinforced by evidence that sustainability disclosure is increasingly value-relevant for European firms (Christofi et al., 2025), while public policy interventions supporting enterprise-level financial resilience appear essential during periods of economic transformation (Alhaimer et al., 2025). Digital leadership and organisational culture further condition the capacity of enterprises to absorb workforce development investments (Basalamah and Basalamah, 2025).

The Energy sector warrants designation as Critical Priority (Tier 1), reflecting its highest skills gap magnitude (mean SGI = 0.162), largest number of high-priority skills requiring intervention (six competencies), and central position in Just Transition objectives. For this sector, we recommend a dual-track workforce transformation strategy. For existing lignite workers, targeted reskilling programs should leverage transferable competencies, such as experience in hazardous environments and sophisticated machinery operation, that facilitate transition to renewable energy technician roles in solar PV and wind installations. The EU-funded RESSKILL project demonstrates that coal workers require only short-course training rather than lengthy vocational programs, given their existing skill base (RES-SKILL, 2023). For new workforce entrants, comprehensive training programs should address the six high-priority competency areas identified in this study, with particular emphasis on green financing and energy storage systems. This dual approach, reskilling existing workers while simultaneously developing new talent pipelines, aligns with EU Just Transition best practices observed in Germany and Poland (European Commission, 2024a).

Green financing module specification. The green financing gap (SGI = 0.331, the largest single deficit identified) warrants a dedicated training component. We propose a short-course module targeting energy project managers, financial officers, and renewable energy engineers, that is, occupations directly involved in capital allocation decisions for green infrastructure. Content should cover: (a) EU Green Deal financing instruments (Just Transition Fund, Innovation Fund, InvestEU), including eligibility criteria and application procedures; (b) bankability assessment for renewable energy projects, including levelised cost calculations and risk-return profiling; (c) green bond standards and sustainability-linked lending criteria; (d) carbon pricing mechanisms and their implications for project economics. Delivery should combine classroom instruction with supervised project work in which participants develop financing plans for actual regional renewable energy projects. Research on financial literacy indicates that it functions as a strategic enterprise resource with measurable performance effects (Ulupui et al., 2025), reinforcing the case for treating this module as a core workforce requirement rather than an elective. Evidence that financial capability functions as a critical determinant of entrepreneurial outcomes alongside entrepreneurial orientation (Karneli et al., 2025) further supports embedding financial competencies within workforce development for capital-intensive transition sectors.

The Construction sector merits High Priority status (Tier 2), characterised by moderate gaps with a clear focus on green skills as the singular priority intervention area. This sector demonstrates the highest adaptation readiness among the three sectors examined and plays a critical role in EU Renovation Wave implementation. However, a critical implementation challenge must be addressed: Greek construction is dominated by micro-enterprises (1–9 employees) that cannot release workers for extended training periods. We propose a modular green building certification pathway designed for this fragmented SME landscape. The certification should comprise three stackable modules, each deliverable as a short intensive: (a) Energy Performance Certificate (EPC) assessment and compliance, targeting site supervisors and foremen; (b) sustainable materials selection and lifecycle assessment, targeting procurement staff and project managers; (c) nearly-zero-energy building (nZEB) construction techniques, targeting skilled tradespeople. Each module should culminate in a competency assessment aligned with the Hellenic Organisation for Standardisation (ELOT) framework, enabling employers to verify outcomes. For resource-constrained SMEs in transition regions, comparable to the ‘everyday entrepreneurs’ described in the digitalisation literature (Braune et al., 2025), practical hands-on certification may be more effective than generic digital literacy programmes. Delivery through existing vocational training centres (KEK) and chambers of commerce would minimise infrastructure costs while leveraging established employer networks. Qualitative evidence from green entrepreneurship contexts indicates that SMEs face distinct challenges in initiating sustainable practices, requiring tailored support strategies rather than generic interventions (Singh et al., 2026).

The ICT sector occupies Strategic Priority position (Tier 3), exhibiting the lowest aggregate gaps but paradoxically the lowest green transition awareness among employers. This sector demonstrates the highest employment growth trajectory, creating substantial absorption capacity for transitioning workers, while playing an enabling role for other sectors’ transformation. The ICT intervention challenge differs fundamentally from Energy and Construction: the skills gaps are technical-digital (DevOps, cybersecurity, cloud), not sustainability-related, yet the sector’s green transition contribution depends on connecting existing digital capabilities with sustainability applications. Generic ‘green awareness’ workshops are unlikely to achieve this connection. Instead, we propose a *sustainability orientation programme* structured around three components. First, a *sector-immersion module* in which ICT professionals spend structured time in Energy and Construction enterprises, learning the operational contexts where their digital tools are deployed; this addresses the awareness gap by making the enabling role concrete rather than abstract. Second, a *green digital solutions lab* in which participants develop prototypes for sustainability applications (smart grid optimisation, building energy management dashboards, carbon footprint tracking systems) using real data from regional enterprises. Third, a *client engagement training* focused on translating technical capabilities into sustainability value propositions for non-technical stakeholders. The disconnect between digital optimism and actual business outcomes documented in other contexts, where strong digital orientation did not translate into superior growth (Kotiranta et al., 2024), reinforces the importance of pairing technical skills with sector-specific application knowledge. Digital platform proficiency appears to predict entrepreneurial opportunity identification more strongly than general entrepreneurial orientation (Troise et al., 2022), suggesting that ICT workers equipped with sustainability domain knowledge may be well-positioned to identify green innovation opportunities in transition regions. Research on technology commercialisation in regulated sectors (Lee and Ljubownikow, 2024) further suggests that combining technical capabilities with domain-specific adaptation skills is essential when deploying solutions in new application contexts, a pattern directly relevant to ICT firms expanding into sustainability service provision.

5.4.2 Regional policy

Regional resource allocation should prioritise Island regions, which exhibit the highest skills gaps across all sectors (Energy SGI = 0.27). Geographic isolation compounds training access challenges, suggesting mobile training units, distance learning platforms, and partnerships with mainland institutions. Western Macedonia, despite its lignite dependency, demonstrates lower gaps warranting maintenance rather than intensive intervention, though longitudinal monitoring is essential to verify this pattern's sustainability.

5.4.3 Education and training

Vocational education institutions should develop sector-specific curricula aligned with the priority skills identified in this study. For Energy, programs should integrate green financing modules alongside technical renewable energy content. For Construction, green building certification pathways should embed within existing craft training. For ICT, sustainability awareness modules should complement technical curricula, emphasising the sector's enabling role in economy-wide decarbonisation. Curriculum reform should prioritise competencies with demonstrated labour market impact (Mohan et al., 2025), particularly the analytical and technology skills identified as critical gaps across the Energy and ICT sectors. Universities and vocational institutions can serve as knowledge exchange hubs connecting sectoral employers with skilled graduates (Boodai and Boodai, 2025).

5.4.4 Employer engagement

Employer engagement strategies should account for the perception-gap disconnect documented in P4. ICT employers require awareness interventions highlighting their sustainability contribution; Energy employers need support navigating financial and strategic (not merely technical) workforce transformation; Construction employers, with highest green awareness, may serve as peer ambassadors for cross-sectoral knowledge transfer. Research on organisational career management indicates that learning culture moderates the relationship between employer investment and employee competence development (Priya and Christopher, 2024), suggesting that skills interventions may be more effective when embedded within broader organisational learning frameworks. Similarly, HRM practices that support knowledge creation and retention facilitate workforce adaptation during periods of structural change (Habtu and Mezgobo, 2024), while adaptive leadership competencies appear critical for navigating the organisational uncertainty inherent in green transition (Jango, 2024). The growing integration of artificial intelligence into human resource management (Bansal et al., 2025) may further reshape how employers in transition regions identify and address competency gaps, underscoring the need to anticipate twin digital-green skill demands in workforce planning.

5.4.5 International best practices

European Just Transition experiences offer relevant lessons. Germany's coal region transition emphasises early stakeholder engagement and long-term planning horizons (mission, 2024a). Poland's retraining programs demonstrate scalable approaches for displaced workers. Spain's renewable energy workforce development illustrates sector-specific curriculum design. These experiences suggest that successful transitions require integrated approaches combining workforce development with broader regional economic diversification strategies. The casualisation of workforce arrangements, increasingly prevalent in transition-affected sectors, undermines systematic skills development and employee performance (Sharma et al., 2025), while green innovation returns are amplified when workforce skills enable effective technology absorption (Yuan et al., 2025). Research on workforce adaptation during economic disruptions comparable to the green transition indicates that enterprises with stronger HRM practices demonstrate greater resilience (Easa et al., 2025). In emerging market economies facing similar sustainability transitions, ESG-oriented enterprises demonstrate greater resilience during periods of disruption (Almaskati, 2025), reinforcing the case for embedding sustainability competencies within core workforce development programmes.

6 Conclusions

6.1 Two central takeaways

This study yields two conclusions that carry direct implications for how Just Transition workforce investment is designed and allocated.

First, resource allocation must follow sector-specific logic. The evidence presented here indicates that skills gaps in Energy, Construction, and ICT are not smaller or larger versions of a common deficit; they are structurally different. Energy requires simultaneous development of financial, strategic, and technical competencies (six high-priority skills, mean SGI = 0.162). Construction faces a single concentrated deficit in green building practices (SGI = 0.238). ICT exhibits minimal aggregate gaps but a critical awareness disconnect regarding its enabling role in sustainability. Pooling training budgets across these sectors, the default approach in many EU Just Transition programmes, risks spreading resources too thinly to address any sector's needs adequately. The Priority Matrix methodology offers an evidence-based alternative: direct the most intensive investment toward Energy (where gaps are deep and multi-dimensional), deliver targeted certification in Construction (where a single deficit is clearly identified), and invest in strategic reorientation rather than technical upskilling for ICT.

Second, employer perceptions of green relevance do not signal workforce readiness. Construction employers report the highest awareness of green transition contribution (M = 3.94) but only one high-priority skills deficit, while Energy employers rate their green relevance modestly (M = 3.52) despite six critical competency gaps. ICT employers perceive minimal green relevance (M = 2.89) despite their sector's highest employment growth. If policymakers rely on employer self-reported green engagement to guide workforce investment, they will over-invest in sectors that feel green and under-invest in sectors that need green competencies. Skills assessment must supplement perception data, not defer to it.

6.2 Contribution to knowledge

Transition Intensity Framework. The study proposes and provides initial empirical support for a transition intensity framework linking the degree of sectoral technological discontinuity to skills gap severity. Building on task-based approaches to green employment (Vona et al., 2018; Consoli et al., 2016), the framework distinguishes three categories: direct transition sectors undergoing fundamental technological substitution (Energy), indirect transition sectors adapting existing practices to new standards (Construction), and enabling sectors facilitating transformation across the economy (ICT). The observed empirical gradient in skills gaps (Energy > Construction > ICT) provides support for this conceptual hierarchy. This framework offers a potentially generalisable analytical tool: by characterising sectors according to their transition intensity, researchers and policymakers in other national contexts may generate testable predictions about relative skills gap magnitudes and intervention priorities.

Sectoral Skills Profiles. The study provides detailed empirical profiles of skills gaps in three key emerging sectors within a Just Transition context. The finding that only one competency (foreign language proficiency) appears across all three sectors supports theoretical frameworks emphasising sectoral embeddedness of green competencies (Bowen et al., 2018; Consoli et al., 2016).

Skills-Contribution Nexus. The study illuminates the relationship between skills gaps, green transition perception, and sectoral contribution potential. The observed inverse relationship between green impact perception and skills gap magnitude suggests that employer perceptions may not accurately signal workforce development priorities.

6.3 Practical contributions

The study translates analytical findings into actionable policy guidance through three practical outputs. First, the *three-tier priority framework* (Critical/High/Strategic) provides national policymakers with evidence-based criteria for allocating limited training resources across sectors. Second, the *sector-specific skills profiles* (Tables 8–10, Appendix A) enable curriculum developers to design targeted training programs addressing documented competency deficits rather than generic sustainability content. Third, the *priority matrix methodology* offers a replicable analytical approach applicable to other Just Transition regions facing similar workforce development challenges. These outputs respond directly to practitioner needs for granular, sector-differentiated guidance navigating the complex terrain of green transition workforce development.

6.4 Limitations and next steps

Each limitation of this study points toward a specific research action that would strengthen the evidence base for Just Transition workforce policy.

The *cross-sectional design* captures employer perceptions at a single timepoint, precluding causal claims about the determinants of skills gaps. *Next step:* Longitudinal tracking of the same enterprises at 2–3 year intervals would reveal whether the observed sectoral gradient is a stable structural feature or a transient condition associated with early-stage transition. The host project framework provides the institutional infrastructure for such follow-up.

The *employer-only perspective* captures demand-side perceptions but omits worker self-assessments. Employer and worker evaluations of competency deficits may diverge systematically: employers in high-scrutiny Just Transition zones may deflate reported gaps due to social desirability, while workers may inflate self-assessed proficiency. *Next step:* A matched employer-worker comparison study, administering parallel instruments to managers and employees within the same enterprises, would quantify the direction and magnitude of this divergence and inform whether training programme design should privilege employer or worker assessments.

The *regional concentration* in Greek Just Transition areas limits generalisability. *Next step:* Applying the Priority Matrix methodology to Just Transition regions in Poland, Germany, or Spain would test whether the transition intensity framework (Energy > Construction > ICT) holds across different institutional and labour market contexts.

Additional limitations include the *three-sector focus* (excluding agriculture and tourism), *employment projections* that represent expectations rather than observed outcomes, and the *sector-specific skill lists* that may have influenced the 91.4% specificity finding. The specificity upper bound/lower bound analysis (Section 4.3) partially addresses the last concern, but independent validation using a common cross-sectoral skill list would provide a definitive test.

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Declarations

All authors declare that they have no conflicts of interest.

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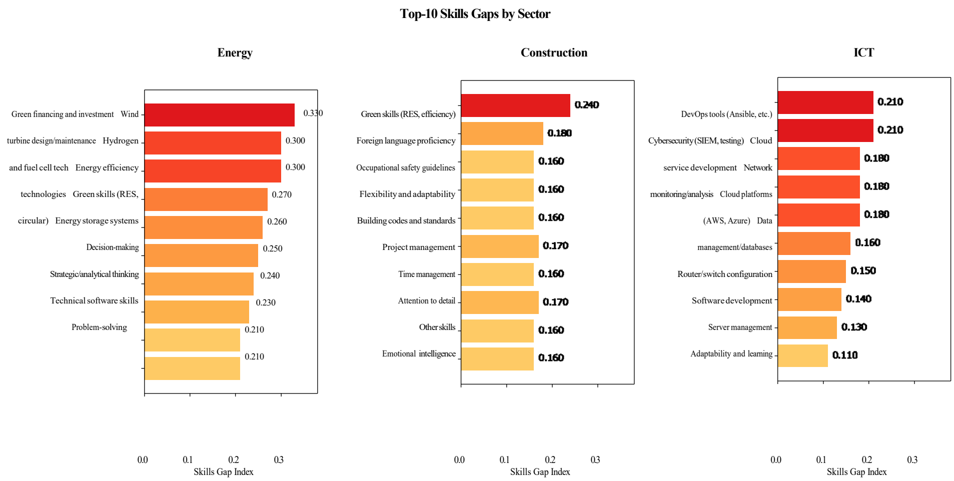
Appendix A: Sectoral skills taxonomies

Figure 3 Top skills comparison across key emerging sectors (see online version for colours)



Notes: Skills ranked by SGI magnitude within each sector. Higher bars indicate larger gaps.

A.1 Energy sector skills (39 competencies)

Table 8 Complete skills assessment: energy sector (top 10)

Category	*Skill*	*Required*	*Current*	*SGI*
Green Finance	Green financing and investment models	3.92	2.62	0.331
Renewable Tech	Wind turbine design and maintenance	2.69	1.88	0.301
Renewable Tech	Hydrogen and fuel cell technology	3.57	2.50	0.300
Energy Efficiency	Energy efficiency technologies	3.70	2.70	0.270
Green Skills	Green skills (RES, efficiency, circular economy)	4.05	2.99	0.262
Renewable Tech	Energy storage systems (lithium-ion, BMS)	3.88	2.91	0.250
Cognitive	Decision-making	4.24	3.21	0.243
Cognitive	Strategic, analytical and creative thinking	3.97	3.06	0.229
Technical	Technical software skills	3.23	2.55	0.211
Cognitive	Problem-solving	4.22	3.35	0.206

A.2 Construction sector skills (23 competencies)

Table 9 Complete skills assessment: construction sector (top 10)

Category	*Skill*	*Required*	*Current*	*SGI*
Green Skills	Green skills (RES, energy efficiency, environment)	4.40	3.35	0.238
Communication	Foreign language proficiency	3.51	2.85	0.178
Safety	Occupational safety guidelines	4.18	3.49	0.163
Soft Skills	Flexibility and adaptability	4.47	3.75	0.161
Regulatory	Building codes and safety standards	3.91	3.30	0.158
Soft Skills	Teamwork and collaboration	4.53	3.87	0.146
Technical	Quality control and inspection	4.12	3.55	0.138
Technical	Construction materials knowledge	4.25	3.68	0.134
Management	Project management	4.08	3.55	0.130
Technical	Blueprint reading and interpretation	4.15	3.62	0.128

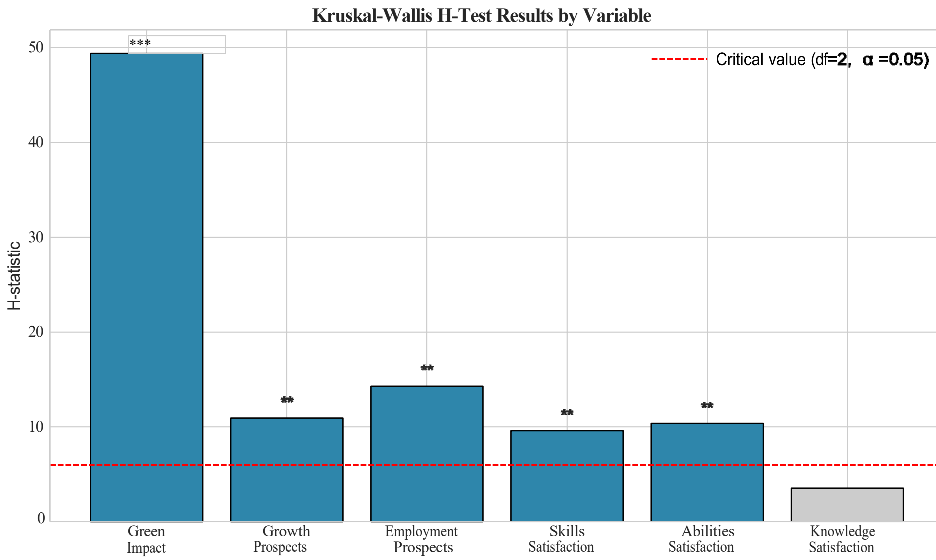
A.3 ICT sector skills (27 competencies)

Table 10 Complete skills assessment: ICT sector (top 10)

Category	*Skill*	*Required*	*Current*	*SGI*
DevOps	DevOps tools (Ansible, Puppet, Jenkins, Kubernetes)	3.34	2.63	0.211
Security	Cybersecurity (SIEM tools, penetration testing)	3.77	2.99	0.206
Cloud	Cloud service development and automation	3.96	3.21	0.183
Networks	Network monitoring and analysis	3.46	2.83	0.183
Cloud	Cloud platforms (AWS, Azure, Google Cloud)	3.92	3.21	0.177
Development	Programming languages (Python, Java, JavaScript)	4.05	3.35	0.173
Data	Database management and SQL	3.88	3.22	0.170
Security	Information security principles	4.01	3.35	0.165
Development	Software development lifecycle	3.85	3.25	0.156
Systems	System administration	3.72	3.15	0.153

Appendix B: Statistical analysis details

Figure 4 Kruskal-Wallis test results: distribution of key variables by sector (see online version for colours)



Notes: Box plots display median, interquartile range, and outliers by sector. Significant differences indicated by H-statistic and p-value.

B.1 Priority classification criteria

Table 11 Priority classification criteria

Priority level	*SGI threshold*	*Required level*	*Intervention type*
High Priority	≥ 0.20	≥ 3.8	Immediate training intervention
Watch	≥ 0.20	< 3.8	Monitor and prepare capacity
Maintain	< 0.20	≥ 3.8	Sustain current training
Low Priority	< 0.20	< 3.8	Deprioritise for resource allocation

B.2 Sensitivity analysis of threshold specifications

Table 12 Sensitivity analysis: priority classification under alternative thresholds

	SGI Threshold Variations			*Required Threshold*	
	≥0.18 (Inclusive)	≥0.20 (Baseline)	≥0.22 (Restrictive)	≥3.7 (Lower)	≥4.0 (Higher)
High-Priority Skills (Total)	9	7	6	9	4
By Sector:					
Energy	7	6	5	7	3
Construction	1	1	1	1	1
ICT	1	0	0	1	0
Sectoral Rankings	E>C=I	E>C>I	E>C>I	E>C=I	E>C>I
Energy Share (%)	78%	86%	83%	78%	75%

Notes: Baseline specification: SGI ≥ 0.20 and Required ≥ 3.8 (sample mean). SGI threshold variations hold Required ≥ 3.8 constant. Required threshold variations hold SGI ≥ 0.20 constant. E = Energy, C = Construction, I = ICT. Sectoral rankings and Energy sector dominance remain stable across all specifications.

Appendix C: Survey instrument summary

C.1 Sample distribution

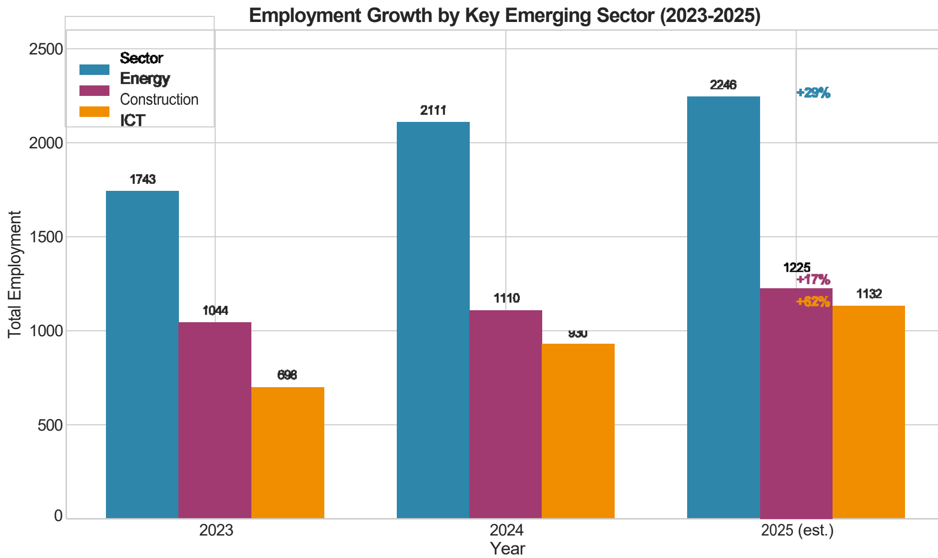
Table 13 Sample distribution by sector and region

Region	*Energy*	*Construction*	*ICT*	*Total*
Western Macedonia	52	78	45	175
Peloponnese	48	85	58	191
Island Regions	40	66	47	153
Total	**140**	**229**	**150**	**519**

Notes: Total sample $N = 1,961$ enterprises; key emerging sectors $n = 519$.

Appendix D: Additional figures and tables

Figure 5 Employment growth trajectories across key emerging sectors, 2023–2025 (see online version for colours)



Notes: Employment figures represent total employees across responding enterprises in each sector. 2025 values are employer projections.

Table 14 Kruskal-Wallis H-test results: cross-sector comparison

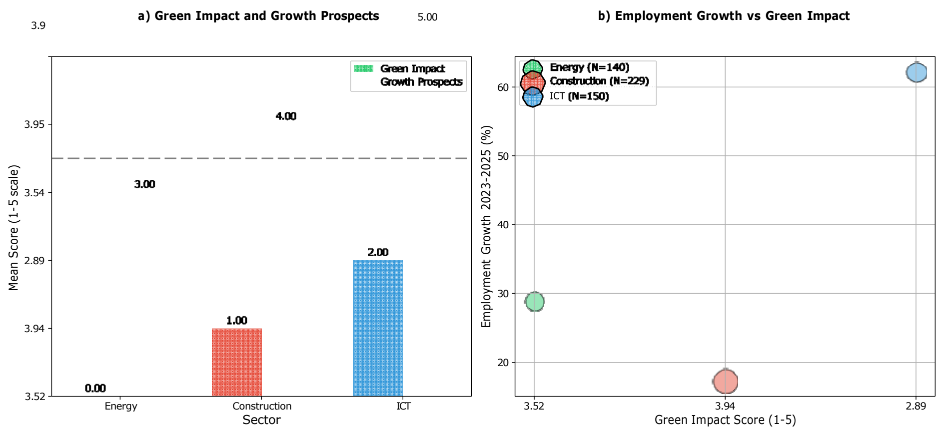
Variable	*H-statistic*	*p-value*	η^2	*Energy*	*Construction*	*ICT*
Skills Gap Index (SGI)	19.07	<0.001***	0.094	0.162[a]	0.144[b]	0.101[c]
Green Impact	49.40	<0.001***	0.133	3.52[a]	3.94[b]	2.89[c]
Growth Prospects	10.93	0.004**	0.025	3.54[a]	3.95[b]	3.90[b]
Employment Prospects	14.28	<0.001***	0.036	3.47[a]	3.93[b]	3.56[a]
Skills Satisfaction	9.60	0.008**	0.028	3.53[a]	3.50[a]	3.88[b]
Abilities Satisfaction	10.36	0.006**	0.031	3.57[a]	3.61[a]	3.96[b]

Notes: SGI values on 0–1 scale (higher = larger gap); other variables on 1–5 Likert scale. Superscript letters indicate significant pairwise differences (Dunn's test, Bonferroni-corrected $p < 0.05$). η^2 = eta-squared effect size. *$p < 0.05$, **$p < 0.01$, ***$p < 0.001$. SGI analysis based on $N = 185$ skill-region observations.

Table 15 Cross-sector skills distribution

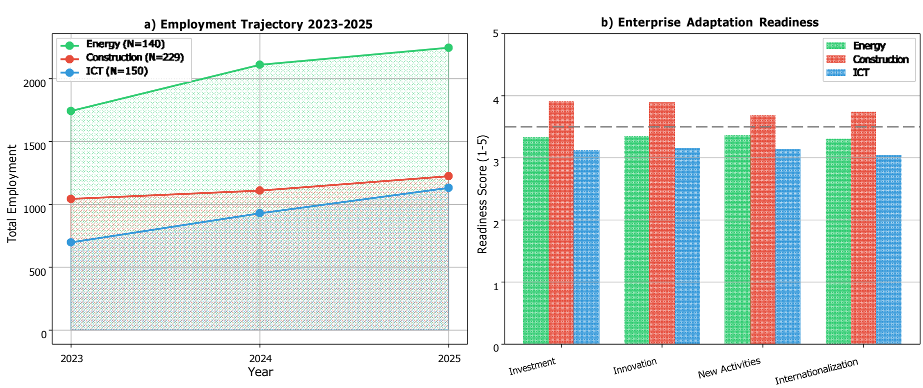
Category	*Count*	*Percentage*
Common to all 3 sectors	1	1.2%
Energy & Construction shared	2	2.5%
Energy & ICT shared	1	1.2%
Construction & ICT shared	3	3.7%
Energy-specific	35	43.2%
Construction-specific	17	21.0%
ICT-specific	22	27.2%
Total unique skills	**81**	**100%**

Figure 6 Green transition contribution and perception by sector (see online version for colours)



Notes: Green impact and growth prospects measured on 1–5 Likert scale. Employment growth represents percentage change 2023–2025.

Figure 7 Future skills demand and enterprise adaptation readiness (see online version for colours)



Notes: Readiness scores represent mean employer ratings on 1–5 Likert scale. Higher values indicate greater adaptation capacity.