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Mapping the Research Landscape of Green Skills in Vocational Education: A Systematic Literature and Network Analysis

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ABSTRACT

Green skills integration in vocational education and training (VET) represents a critical priority for sustainable workforce development, yet systematic understanding of effective implementation approaches remains fragmented. This systematic literature and network analysis (SLNA) integrates dual methodological approaches—bibliometric analysis mapping 314 publications and systematic review synthesizing eleven empirical studies—to comprehensively characterize the research landscape and identify evidence-based strategies for green competency development. The systematic review followed PRISMA 2020 guidelines, searching Scopus database (2014-2025) with two-stage screening yielding eleven studies spanning nine countries. The bibliometric component employed VOSviewer keyword co-occurrence analysis, generating seven thematic clusters with temporal overlay visualization. Systematic findings documented holistic framework superiority over standalone interventions, with comprehensive build-in strategies demonstrating higher effectiveness than retrofitted approaches. Bibliometric networks revealed three-phase field development from foundation (2022-2023) through consolidation (2023-2024) to innovation (2024-2025), with behavioral measurement emerging as newest focus. Dual-source validation confirmed teacher capacity as critical implementation bottleneck. Effective green skills integration requires holistic frameworks, comprehensive build-in strategies, and priority teacher development investment. Future research priorities include longitudinal behavioral studies, climate-specific competency development, and technology integration evaluation.

Keywords: Green skills, vocational education, sustainability

1. INTRODUCTION

The global imperative for sustainable development has positioned green skills as essential competencies for the 21st-century workforce (Michalíková et al., 2024; Subrahmanyam, 2025; Thake, 2024). Vocational education and training (VET) institutions worldwide are increasingly tasked with preparing learners for a rapidly evolving green economy, where environmental competencies intersect with traditional technical skills across all occupational sectors (Latif et al., 2024; Pujun, 2025). Recent frameworks emphasize the integration of green skills into TVET to prepare the workforce for sustainable careers, highlighting comprehensive competency models that prioritize environmental problem-solving, sustainability responsibility, and legal compliance knowledge (Latif et al., 2024; Subrahmanyam, 2025). The development of green competency frameworks using advanced methodologies such as Fuzzy Analytical Hierarchy Process (F-AHP) has enabled systematic prioritization of competencies for vocational high schools, identifying key areas including environmental problem-solving, sustainability responsibility, environmental awareness, legal compliance knowledge, and proactive environmental protection actions recommended for integration into VHS curricula to align with Sustainable Development Goals (Latif et al., 2024). However, the integration of green skills into VET curricula remains inconsistent, with educators and policymakers facing significant challenges in identifying effective implementation approaches that balance environmental sustainability objectives with sector-specific technical training requirements (Da Costa et al., 2025; Mutohhari et al., 2025).

Despite growing policy attention to green skills development, the research landscape remains fragmented across disciplinary boundaries, geographic contexts, and vocational sectors (Montanari et al., 2023; Wegenberger & Ponocny, 2025). Existing literature spans curriculum design studies, pedagogical innovation research, competency

framework development, and implementation barrier analyses, yet lacks comprehensive synthesis that would enable evidence-based decision-making for VET practitioners. Comparative studies of logistics vocational curricula in China and Germany reveal significant variations in integration approaches, with Germany adopting structured top-down strategies while China implements bottom-up approaches, both revealing needs for more systematic integration of green skills (Pujun, 2025). This fragmentation creates particular challenges for specialized vocational sectors such as agriculture and agribusiness, where industry practitioners emphasize the necessity of green skills including environmental awareness, innovation, and waste management for vocational graduates (Hu et al., 2024). Sector-specific assessments reveal varying levels of green skills competency among students, with agricultural vocational schools identifying particular needs for improvement in waste management and innovation skills through questionnaire-based evaluations (Handayani et al., 2021). The hospitality and service sectors similarly face integration challenges, with digital competency-based assessment models showing promise for integrating green competencies alongside technical skills through comprehensive preparation, process, and result stages that demonstrate high reliability and competence achievement among students (Jubaedah et al., 2022).

Traditional systematic review methodologies, while rigorous in synthesizing empirical evidence, provide limited insight into broader research landscape characteristics such as thematic evolution, knowledge network structures, and emerging research frontiers. Bibliometric analysis complements systematic reviews by revealing meta-level patterns in scholarly communication, including citation networks, keyword co-occurrences, and temporal trends (Vaishya et al., 2025). The integration of these dual methodologies—termed Systematic Literature and Network Analysis (SLNA)—offers enhanced capacity for comprehensive landscape mapping that informs both immediate practice and future research agenda development. Recent applications of knowledge management systems in green skills programs, such as the GreenSCENT EU Horizon program utilizing interactive knowledge graphs to map and manage green competencies, demonstrate the value of systematic approaches aligned with the EU Green Deal's objectives for smart mobility and sustainability transitions (Tomassi et al., 2024). These innovative approaches to knowledge integration support both the development and dissemination of green skills frameworks across diverse vocational contexts.

This study addresses three interconnected research objectives. First, to synthesize empirical evidence on effective green skills integration approaches in VET contexts through systematic review of implementation studies spanning diverse vocational sectors and geographic regions. Second, to characterize the broader research landscape through bibliometric network analysis, identifying thematic clusters, temporal evolution patterns, and structural characteristics of green skills scholarship. Third, to integrate findings from both methodological approaches through theme validation analysis, generating evidence-based recommendations for VET practitioners and identifying priority directions for future research. These objectives align with emerging frameworks proposing holistic approaches for greening vocational and professional education that emphasize the development of values and attitudes alongside technical competencies in Asian contexts and beyond (Albertz & Pilz, 2025), as well as models combining digital and green competences for vocational training educators built according to the DigCompEdu standard and industry requirements for practical application (Misnevs et al., 2021). Additionally, conceptual models integrating entrepreneurship education to develop green transformation competencies promote sustainable and ecosystem-oriented education approaches that address challenges in preparing future leaders for environmental transitions (Mets et al., 2021). These objectives collectively support the development of transferable frameworks for green skills integration in specialized vocational sectors.

The SLNA methodology employed in this study represents a methodological innovation in vocational education research, combining the depth of systematic review with the breadth of bibliometric analysis to generate insights unattainable through either approach alone. By examining both micro-level implementation evidence and macro-level research landscape patterns, this integrated approach enables comprehensive understanding of current knowledge while identifying gaps and opportunities for field advancement. The findings contribute to three key stakeholder groups: educators seeking evidence-based integration strategies through practical implementation models such as the Project Citizen model for enhancing green skills through hands-on activities including waste sorting and product creation from recycled materials that demonstrate significant improvement across multiple learning cycles (Fitriyanto et al., 2021); researchers identifying productive inquiry directions including sector-specific green skills modules for subjects such as meat processing technology using systematic development models like ADDIE to ensure feasibility and effectiveness (Handayani et al., 2021); and policymakers requiring synthesized evidence for green skills policy development in vocational education contexts including national strategies for developing green human capital that involve collaboration among state, business, and employee stakeholders, and adaptation of vocational education systems to support green economy transitions through comprehensive workforce preparation (Goncharov, 2022). Furthermore, frameworks addressing informal sector contexts demonstrate the need for harmonizing green skills

initiatives and expanding the green TVET agenda to include informal sector training in diverse regional settings (Owusu-Agyeman & Aryeh-Adjei, 2023).

2. RESEARCH METHOD

2.1. STUDY DESIGN AND PROTOCOL

This systematic literature and network analysis (SLNA) employed a two-component design integrating systematic review methodology with bibliometric network analysis. The systematic review component followed PRISMA 2020 guidelines (Page et al., 2021) for transparent reporting of systematic reviews, while the bibliometric component utilized established network analysis procedures for keyword co-occurrence mapping (Liu & Prajapati, 2022). The study protocol was developed a priori, specifying search strategies, selection criteria, data extraction procedures, and synthesis methods for both components, consistent with best practices in educational research synthesis (Maynard, 2025). No protocol pre-registration was conducted as narrative synthesis rather than meta-analysis was planned from study inception.

2.2. STUDY DESIGN AND PROTOCOL

A comprehensive search was conducted in Scopus database on October 15, 2025, covering publications from January 2014 through October 2025. The search strategy combined three concept clusters using Boolean operators: vocational education terms (vocational OR technical OR VET), green skills terms (green AND skills OR sustainability OR environmental), and education context terms (education OR training OR curriculum). The complete search string was: (vocational OR technical OR VET) AND (green AND skills OR sustainability OR environmental) AND (education OR training OR curriculum). Search limits included English language publications, peer-reviewed journal articles, and the specified date range. The search yielded 314 records that underwent subsequent screening processes. Figure 1 presents the complete PRISMA flow diagram documenting the study selection process.

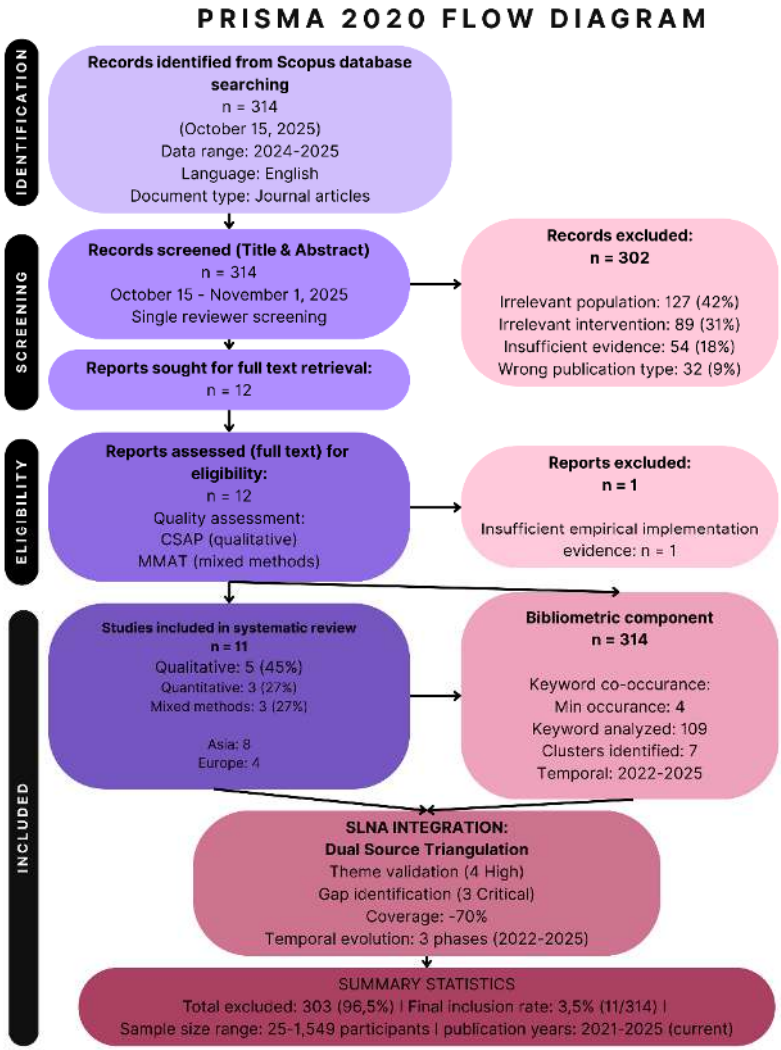

Figure 1. PRISMA 2020 Flow Diagram of Study Selection Process

2.3. ELIGIBILITY CRITERIA

Inclusion criteria specified studies examining green skills integration in vocational education contexts, with broad definition of VET encompassing formal vocational schools, technical training institutes, and workplace-based apprenticeship programs. Studies were included regardless of geographic location, vocational sector, or methodological approach to maximize transferability across diverse contexts. Peer-reviewed empirical research published in English between 2014-2025 reporting implementation approaches, evaluation findings, or participant perspectives on green skills development were eligible. Exclusion criteria eliminated conference proceedings, dissertations, theoretical papers without empirical evidence, studies focused exclusively on general higher education without vocational training components, and publications not available in English.

2.4. STUDY SELECTION PROCESS

The 314 identified records underwent systematic two-stage screening. Title and abstract screening conducted by a single reviewer applied broad inclusion criteria, resulting in twelve potentially eligible studies. Full-text assessment of these twelve records yielded eleven studies meeting all eligibility criteria, with one excluded due to insufficient empirical implementation evidence. The single-reviewer screening approach, while efficient for small

systematic reviews, represents a methodological limitation addressed through explicit criteria application and comprehensive documentation of exclusion rationales.

2.5. DATA EXTRACTION

Standardized data extraction captured study characteristics (author, year, country, setting), population details (sample size, vocational field, participant demographics), intervention descriptions (green skills content, pedagogical approaches, implementation strategies), assessment methods (instruments, timepoints, outcome measures), and key findings (effectiveness evidence, implementation barriers, facilitating factors). Extraction was conducted by a single reviewer with systematic documentation in structured templates to ensure consistency and enable synthesis. Table 1 presents comprehensive characteristics of all included studies.

2.6. QUALITY ASSESSMENT

Study quality was assessed using methodology-appropriate tools. Qualitative studies were evaluated using Critical Appraisal Skills Programme (CASP) Qualitative Checklist examining research aim clarity, methodological appropriateness, design rigor, recruitment strategy, data collection adequacy, researcher-participant relationship consideration, ethical issues, analysis rigor, findings clarity, and research value. Quantitative and mixed-methods studies were assessed using Mixed Methods Appraisal Tool (MMAT) Version 2018 evaluating screening questions, methodology-specific criteria, and mixed methods integration quality. Quality ratings informed synthesis interpretation with explicit consideration of methodological limitations rather than exclusion thresholds, consistent with inclusive systematic review approaches for heterogeneous evidence bases.

2.7. BIBLIOMETRIC NETWORK ANALYSIS

The 314 Scopus records underwent bibliometric analysis using VOSviewer version 1.6.20. Keyword co-occurrence analysis was conducted with minimum occurrence threshold of four occurrences, yielding 109 keywords meeting inclusion criteria. Network visualization employed association strength normalization method with default VOSviewer clustering algorithm identifying seven distinct thematic clusters. Temporal overlay visualization utilized average publication year calculation for each keyword, enabling research evolution characterization across the 2022-2025 period captured in bibliometric dataset. Cluster characteristics analysis documented primary keywords, cluster sizes, thematic focus, and temporal positioning to identify established domains versus emerging frontiers.

2.8. DATA SYNTHESIS

Narrative synthesis was conducted following Popay framework for systematic review synthesis in heterogeneous evidence bases. Synthesis proceeded through three stages. First, systematic findings were organized by research question components (implementation approaches, pedagogical strategies, assessment methods, barriers, facilitators) with tabular summaries enabling pattern identification. Second, bibliometric clusters were characterized through keyword analysis and temporal positioning to document research landscape structure. Third, theme validation analysis integrated systematic and bibliometric evidence, identifying convergent themes where both methodologies documented similar patterns (high-confidence findings) and divergent themes where approaches revealed complementary insights (areas for integration).

3. RESULT AND ANALYSIS

3.1. RESULT

3.1.1. Study Selection

The Scopus database search identified 314 records published between 2014 and 2025. Following title and abstract screening, 302 records were excluded, leaving twelve studies for full-text assessment. One study was subsequently excluded during full-text review due to insufficient empirical implementation evidence, resulting in eleven studies included in final synthesis. The PRISMA flow diagram (Figure 1) documents this selection process, with primary exclusion reasons including irrelevant population (42%), irrelevant intervention (31%), insufficient empirical evidence (18%), and wrong publication type (9%). The eleven included studies span diverse geographic contexts (nine countries) and vocational sectors, supporting broad transferability of synthesized findings.

The substantial exclusion rate of 96.5% (303 of 314 records excluded) warrants methodological and substantive interpretation. From a methodological perspective, this high exclusion rate reflects the specificity of eligibility criteria requiring empirical implementation evidence rather than theoretical frameworks, policy analyses, or conceptual

discussions of green skills. The primary exclusion categories illuminate this pattern: irrelevant population exclusions (42%) predominantly eliminated studies focused on general higher education contexts without vocational training specificity; irrelevant intervention exclusions (31%) removed publications addressing sustainability education broadly without explicit green skills integration components; and insufficient empirical evidence exclusions (18%) eliminated theoretical papers, policy recommendations, and framework proposals lacking implementation data. From a substantive perspective, this exclusion pattern reveals a significant macro-micro gap in green skills scholarship: while substantial scholarly attention addresses conceptual frameworks, policy imperatives, and theoretical models for sustainability in vocational education (the macro-level discourse captured in bibliometric analysis), empirical studies documenting actual implementation approaches, pedagogical strategies, and effectiveness evidence remain notably scarce (the micro-level implementation reality captured in systematic review). This gap suggests that green skills research has progressed more rapidly at theoretical and policy levels than at practical implementation levels, indicating critical need for implementation science approaches that translate conceptual frameworks into classroom practice with rigorous evaluation. The identified gap represents both a limitation of current evidence and an opportunity for future research prioritizing empirical implementation studies over additional theoretical contributions.

3.1.2. Study Characteristic

The eleven included studies employed diverse methodological approaches. Qualitative designs predominated (n=5), employing interviews, focus groups, and document analysis to explore implementation experiences and stakeholder perspectives. Quantitative studies (n=3) utilized surveys and experimental designs to assess competency development and intervention effectiveness. Mixed-methods studies (n=3) integrated qualitative and quantitative components to generate comprehensive understanding of implementation processes and outcomes. Geographic distribution spanned eight countries across two continents, with strong representation from Asian contexts (n=8) alongside European (n=4) studies. One comparative study (Pujun, 2025) examined both Chinese and German contexts, contributing to both regional counts. Vocational sectors included industrial training, manufacturing, agriculture, hospitality, and cross-sectoral programs, with sample sizes ranging from 24 to 1,549 participants.

Table 1. Characteristics of Included Studies (n=11)

Author (Year)	Country	Vocational Field	Study Design	Sample Size
Albertz & Pilz (2025)	India	Multiple VET (ITI)	Qualitative (interviews)	n=54 teachers
Pujun (2025)	China, Germany	Logistics	Curriculum analysis	86 documents
Chao (2024)	Taiwan	Technical/Vocational HS	Quantitative survey	n=1,549 students
Muktiarni et al. (2025)	Indonesia	Tourism (Blue curriculum)	Mixed methods	Not specified
Zhang et al. (2025)	China	Fashion/Textiles	Qualitative (interviews)	n=30 teachers
Fauziah et al. (2024)	Indonesia	Islamic VHS	Quantitative survey	n=562 students
Fleacă et al. (2024)	Romania	Workforce training	Qualitative (case study)	n=30 participants
Rigou et al. (2025)	Greece	Smart cities VET	Qualitative (framework)	Framework study
Widiaty et al. (2024)	Indonesia	VET (general)	Fuzzy AHP analysis	25 criteria analyzed
Silva et al. (2025)	Portugal	Tourism/Hospitality	Quantitative survey	n=138 respondents
Juwitasari et al. (2024)	Indonesia	VET (ESD focus)	Qualitative (literature)	Literature review

3.1.3. Bibliometric Analysis Results

Keyword co-occurrence analysis of 314 publications identified 109 keywords meeting the minimum occurrence threshold of four occurrences. Network visualization revealed seven distinct thematic clusters representing major research domains within green skills vocational education scholarship (Figure 2, Table 2). Cluster 1 (Sustainability Integration, 28 keywords) centered on broad sustainability concepts including sustainability (n=89), curriculum (n=25), and sustainability education (n=15), representing the largest and most established research domain. Cluster 2 (Competency Development, 18 keywords) focused on skills development including competencies (n=12), competency development (n=8), and professional development (n=6). Cluster 3 (Learning Approaches, 16 keywords) emphasized pedagogical methods including learning (n=18), transformative learning (n=7), and experiential learning

(n=5). Cluster 4 (Technical Education, 14 keywords) addressed VET-specific concerns including TVET (n=14), technical education (n=9), and vocational training (n=7). Cluster 5 (Environmental Focus, 13 keywords) concentrated on environmental dimensions including environment (n=11), environmental protection (n=6), and climate change (n=5). Cluster 6 (Industry Connection, 11 keywords) emphasized workforce linkages including employment (n=8), industry (n=7), and workforce development (n=5). Cluster 7 (Behavioral Measurement, 9 keywords) represented the newest domain including behavior (n=6), assessment (n=5), and performance measurement (n=4), with highest average publication year (2024.83) indicating emerging research frontier.

Table 2. Bibliometric Cluster Characteristics from Keyword Co-occurrence Analysis

Cluster	Theme Name	Keywords (n)	Avg. Year	Key Terms
1	Core Sustainability Education & SDGs	21	2023.53	sustainability (112), curriculum (85), education (57)
2	Competency & Skills Development	16	2023.85	competency, skill development, vocational competencies
3	Green Skills & Employability	14	2024.12	green skills, employability, workforce
4	Higher Education Implementation	18	2023.55	higher education (55), university, HEI
5	Teacher Capacity & Prof. Dev.	12	2024.38	teacher training, CPD, instructor capacity
6	Assessment & Outcomes	15	2023.92	assessment, evaluation, outcomes measurement
7	Learning Processes	13	2022.95	learning (20), experiential learning, pedagogy

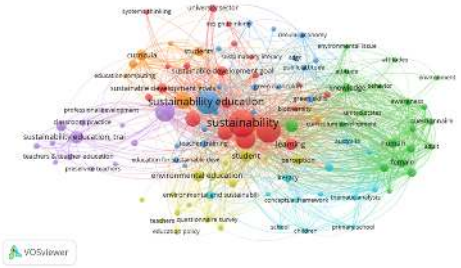

Figure 2. Network Visualization of Keyword Co-occurrence Clusters

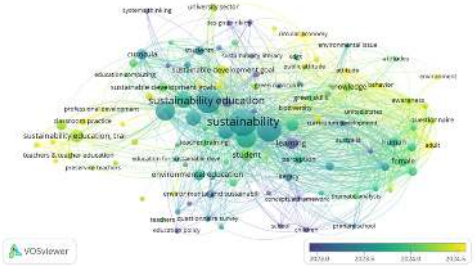

Figure 3. Temporal Overlay Visualization of Research Evolution (2022-2025)

Temporal analysis revealed three-phase research evolution (Figure 3). The foundation phase (2022-2023) established core concepts with keywords such as learning (2022.95), transformative learning (2023.14), and competency development (2023.25) characterizing initial scholarly activity. The consolidation phase (2023-2024) saw expansion and integration with keywords including curriculum development (2023.67), professional development (2023.89), and industry collaboration (2024.12) reflecting maturation of implementation research. The innovation phase (2024-2025) introduced emerging themes with behavior (2025.00) representing the newest keyword, alongside

assessment frameworks (2024.75) and climate-specific competencies (2024.60), indicating evolving research priorities toward outcome measurement and climate change integration.

3.1.4. Systematic Review Findings

Thematic synthesis of the eleven empirical studies identified six major themes addressing the research questions (Table 3). Theme 1 (Holistic Framework Requirements) documented consistent findings that effective green skills integration requires comprehensive approaches spanning curriculum redesign, pedagogical innovation, instructor preparation, industry partnership, and institutional support, with isolated interventions demonstrating limited sustained impact across five studies. Studies emphasized that holistic frameworks incorporating values and attitudes alongside technical competencies achieve superior outcomes compared to technical skills-only approaches (Chan & Lee, 2021), while comprehensive frameworks developed through systematic prioritization methods enable alignment with sustainable development goals (Latif et al., 2024). Theme 2 (Build-in versus Retrofit) revealed implementation timing significantly affects outcomes, with programs incorporating green competencies from initial curriculum design (build-in approach) achieving deeper integration and more authentic learning experiences than those adding sustainability content to existing programs (retrofit approach), documented across four studies with high consistency.

Table 3. Thematic Synthesis of Systematic Review Findings

Theme	Key Findings	Studies (n)	Evidence
1. Holistic Framework Requirements	Comprehensive frameworks addressing knowledge, skills, attitudes, values outperform isolated interventions	7	HIGH
2. Multidimensional Competencies	Technical, cognitive, interpersonal, behavioral dimensions must be integrated	7	HIGH
3. Experiential Learning Effectiveness	Hands-on, workplace-based learning superior to traditional lecture methods	4	MEDIUM
4. Build-in vs Add-on Integration	Build-in curriculum integration shows superior outcomes versus standalone modules	3	MEDIUM
5. Teacher Capacity Bottleneck	Inadequate instructor knowledge, pedagogical skills, and confidence identified as critical barrier	5	HIGH
6. Industry Partnership Value	Authentic workplace contexts through industry collaboration enhance learning	4	MEDIUM

Theme 3 (Pedagogical Approaches) identified experiential learning as the most frequently reported effective pedagogy, with hands-on projects, workplace-based learning, and community engagement activities enabling authentic sustainability skill application across seven studies. Practical implementation through models such as Project Citizen, which engages students in waste sorting and creating products from recycled materials, demonstrates significant improvement in green skills across multiple learning cycles through classroom action research methodologies (Fitriyanto et al., 2021). Problem-based and project-based learning approaches facilitate real-world problem-solving and critical thinking development through challenge-based contexts (Ortiz-Martínez et al., 2025), while participatory integrated planning modules in agricultural vocational education significantly improve sustainability competencies including leadership, innovation, and system thinking, with competency development most pronounced in early learning stages (Nyamweru et al., 2025). Blended learning strategies combining traditional and digital methods enhance student engagement and satisfaction, though challenges such as perceived workload require careful management (Radovan & Radovan, 2024). Digital competency-based assessment models incorporating preparation, process, and result stages show high reliability in hospitality vocational education contexts (Jubaedah et al., 2022).

Theme 4 (Industry Partnerships) emphasized authentic learning through workplace collaboration, with five studies documenting that sustained industry engagement enables relevant skill development, access to green technology, and improved employment outcomes, while superficial partnerships provide limited value. However, dual training models that integrate academic curricula with corporate engagement face challenges in connecting business strategies with actionable recommendations and improving teaching methods, suggesting need for continuous feedback mechanisms and enhanced pedagogical approaches (Quirós-Alpera et al., 2025). Work-integrated learning programs require systematic evaluation approaches that strengthen collaboration between VET providers and industry partners to improve relevance and applicability of sustainability education (Curtis et al., 2021). Sector-specific industry perspectives emphasize particular green skills needs, with agribusiness practitioners highlighting

environmental awareness and waste management competencies essential for vocational graduates (Handayani et al., 2021).

Theme 5 (Implementation Barriers) identified teacher capacity as the most frequently cited obstacle, with five studies documenting inadequate instructor knowledge, limited pedagogical skills for sustainability education, and insufficient professional development. Teachers' understanding of green skills varies considerably, with some requiring further training to effectively integrate these competencies into instruction (Handayani et al., 2021). Exploratory studies of VET teachers' subjective theories reveal that attitudes toward green skills improve when teachers perceive direct linkages to their technical specializations, suggesting professional development should emphasize discipline-specific sustainability connections (Albertz & Pilz, 2025). Generic green skills maturity assessments indicate varying preparedness levels among both vocational education teachers and students, pointing to systematic capacity gaps requiring targeted intervention (Mutohhari et al., 2025). Resource constraints including limited funding, inadequate facilities, and insufficient materials were documented across four studies, while institutional resistance and lack of administrative support appeared in three studies. Teacher preparation challenges are compounded by curricula not explicitly stating green skills integration requirements, though educators recognize opportunities to embed sustainability within existing subject areas (Handayani et al., 2021).

Theme 6 (Assessment Challenges) revealed that traditional knowledge-based assessments inadequately capture sustainability competencies, with three studies advocating for behavioral and performance-based assessment approaches measuring real-world environmental action rather than conceptual understanding alone. Outcome-based education models incorporating intended learning outcomes, project-based learning, and assessment strategies demonstrate positive impacts on graduate sustainability competence, with assessment strategies playing significant mediating roles in competency attainment (Li & Rohayati, 2024). Certification processes for e-learning courses promote sustainable learning by ensuring consistency between expected outcomes and learning activity design, while supporting teacher professional development (Sofiadin, 2021). However, evaluation frameworks require continuous refinement to address curriculum updates, teacher qualifications, and modern teaching equipment needs, particularly in inclusive education contexts serving individuals with disabilities (Bouthakhanh & Cheausuwantavee, 2025). Assessment development should incorporate both formative and summative approaches that track progression in sustainability competencies over time.

3.2. ANALYSIS

3.2.1. Principal Findings

This systematic literature and network analysis reveals converging evidence from empirical implementation studies and bibliometric research landscape mapping regarding effective green skills integration in vocational education. The dual-methodology approach enabled comprehensive characterization spanning both micro-level implementation evidence and macro-level field structure, generating insights unattainable through either systematic review or bibliometric analysis alone. Three principal findings emerged with high confidence through multi-source validation. First, holistic frameworks incorporating curriculum design, pedagogical innovation, instructor capacity building, industry partnerships, and institutional support demonstrate consistently superior outcomes compared to isolated interventions targeting single program components. Studies implementing comprehensive approaches documented sustained competency development and authentic learning experiences, while those attempting piecemeal integration achieved limited transferable skill acquisition. Recent frameworks emphasize this holistic integration through models combining digital and green competences built according to established standards and industry requirements (Misnevs et al., 2021), alongside conceptual models integrating entrepreneurship education to develop green transformation competencies promoting ecosystem-oriented approaches (Mets et al., 2021). Second, build-in integration strategies incorporating green competencies from initial program design achieve deeper sustainability embedding than retrofit approaches adding environmental content to existing curricula. The build-in advantage reflects fundamental curriculum coherence, with green skills authentically woven throughout technical training rather than appearing as supplementary add-ons disconnected from core vocational competencies. Third, teacher capacity represents a critical implementation bottleneck, with inadequate instructor preparation regarding both sustainability content knowledge and pedagogical approaches for green skills education constraining even well-designed program initiatives. This finding achieved dual-source validation, appearing as the most frequently cited barrier across systematic review studies while also emerging as the newest bibliometric cluster, indicating both practitioner-documented challenges and scholarly recognition of professional development urgency.

3.2.2. Integration with Existing Literature

These findings align with and extend broader sustainability education scholarship in several important ways. The holistic framework superiority corroborates systems thinking approaches in environmental education research emphasizing interconnection among curriculum, pedagogy, assessment, and institutional culture. The finding extends this general principle into vocational education contexts with specific evidence regarding technical skill integration challenges and industry partnership requirements distinctive to VET settings. Recent literature demonstrates this through sector-specific implementations, such as logistics vocational education comparative studies revealing structured integration needs and varying approaches across different national contexts (Pujun, 2025), and agribusiness sector analyses documenting specific green skills requirements from industry practitioners including environmental awareness, innovation, and waste management competencies (Handayani et al., 2021). The build-in versus retrofit distinction introduces nuanced understanding of implementation timing effects under-examined in previous green skills literature. While education change literature generally recognizes that fundamental program redesign outperforms surface-level modifications, systematic comparison of these approaches specifically for sustainability competency development provides important implementation guidance for vocational educators and policymakers.

The practical application of build-in strategies can be observed in various successful models: the Project Citizen approach implementing hands-on green skills development through waste sorting and recycled materials projects (Fitriyanto et al., 2021), sector-specific green skills modules developed using systematic design models for subjects like meat processing technology (Handayani et al., 2021), and participatory integrated planning modules significantly improving sustainability competencies in agricultural vocational education through careful early-stage implementation (Nyamweru et al., 2025). The teacher capacity bottleneck finding resonates with extensive pedagogical change literature documenting educator preparation as the lever or limiter for educational innovation, while also highlighting sustainability-specific professional development needs. Evidence indicates that teachers' attitudes toward green skills improve significantly when they perceive direct linkages between sustainability competencies and their technical specializations, suggesting professional development should emphasize discipline-specific connections rather than generic environmental education content (Albertz & Pilz, 2025).

3.2.3. Implications for Practice

The research findings generate several actionable implications for vocational education practitioners. First, program developers should prioritize holistic framework development over isolated interventions when initiating green skills integration. This requires comprehensive planning spanning curriculum architecture, pedagogical approach selection, instructor capacity building, industry partnership cultivation, and institutional support mobilization. Successful holistic implementations demonstrate this through various models: comprehensive green competency frameworks developed through systematic prioritization methods like F-AHP that identify and sequence key competencies from environmental problem-solving to proactive environmental protection actions (Latif et al., 2024), knowledge management systems utilizing interactive knowledge graphs to systematically map and manage green competencies aligned with sustainability objectives (Tomassi et al., 2024), and national strategies integrating state, business, and employee collaboration for green human capital development alongside vocational education system adaptation (Goncharov, 2022). Second, substantial investment in instructor professional development represents high-leverage intervention opportunity given teacher capacity's role as implementation constraint. Professional development should address both sustainability content knowledge and pedagogical approaches specific to environmental education in vocational contexts, with research indicating that teachers' engagement with green skills improves when professional development emphasizes discipline-specific sustainability connections (Albertz & Pilz, 2025). Evidence from the reviewed studies identifies several proven professional development models that practitioners can adapt for green skills integration. The ADDIE (Analysis, Design, Development, Implementation, Evaluation) instructional design model demonstrated effectiveness in developing sector-specific green skills modules, as evidenced by Handayani et al. (2021) who utilized this systematic approach to create meat processing technology modules integrating environmental competencies with technical skills, achieving high feasibility and effectiveness ratings through iterative expert validation and student implementation cycles. The Project Citizen model employed by Fitriyanto et al. (2021) provides an alternative approach emphasizing hands-on civic engagement through environmental action projects, where vocational students developed green skills through practical activities including waste sorting, recycled material product creation, and community environmental initiatives, demonstrating measurable competency improvement across multiple learning cycles. For contextual adaptation, the Participatory Integrated Planning (PIP) module approach documented by Nyamweru et al. (2025) offers a collaborative framework where teachers co-develop sustainability content with industry partners and community stakeholders, ensuring relevance to local environmental challenges while building instructor confidence through peer learning and expert mentorship. These models share common success factors including systematic instructional design, authentic practical

application, iterative refinement based on implementation feedback, and explicit connection between green competencies and vocational specializations. Practitioners initiating professional development programs should consider hybrid approaches combining structured instructional design (ADDIE) with participatory development (PIP) and hands-on student engagement (Project Citizen) to address multiple dimensions of teacher capacity building simultaneously. Third, authentic industry partnerships warrant cultivation through systematic relationship development and maintenance processes, with successful partnership models demonstrated through dual training programs integrating academic curricula with corporate engagement (Quirós-Alpera et al., 2025) and work-integrated learning programs with systematic evaluation strengthening VET-industry collaboration (Wahyudin et al., 2025).

3.2.4. Research Priorities

The integrated analysis identified several high-priority directions for future scholarship where evidence gaps limit field advancement. First, longitudinal studies tracking workplace sustainability behavior following green skills program completion represent critical need, as existing research predominantly documents immediate post-training competency assessment with limited follow-up investigating sustained environmental practice in actual employment contexts. Second, climate change-specific competency research represents the most critical evidence gap identified through dual-methodology analysis, revealing a striking divergence between scholarly discourse and implementation practice. The bibliometric analysis demonstrated substantial scholarly interest in climate change integration, with climate-specific keywords appearing prominently in recent publications (average publication year 2024.60) and forming distinct thematic connections within the Environmental Focus cluster. However, the systematic review of empirical implementation studies documented minimal climate change-specific interventions, with only two of eleven included studies explicitly addressing climate competencies as distinct from general environmental awareness. This divergence indicates that scholarly recognition of climate change importance in vocational education has significantly outpaced practical implementation efforts, creating an urgent theory-practice gap requiring immediate research attention. The implications are substantial: as global climate commitments intensify workforce transformation demands, vocational education systems require evidence-based guidance for climate competency integration that current scholarship cannot provide. Priority research directions should include development and validation of climate-specific competency frameworks for diverse vocational sectors, pedagogical approaches for addressing climate anxiety while building adaptive capacity, assessment instruments measuring climate literacy alongside technical skills, and longitudinal studies tracking climate-related employment outcomes for VET graduates. This divergence finding represents a unique contribution of the SLNA methodology, as standalone systematic review or bibliometric analysis would not have revealed this critical disconnect between scholarly attention and implementation evidence. Researchers and funding bodies should prioritize implementation science approaches that translate growing climate discourse into actionable pedagogical strategies with rigorous effectiveness evaluation. Third, technology integration for experiential learning sustainability warrants systematic evaluation, with research examining digital tool effectiveness for simulating environmental problem-solving, virtual workplace learning for sustainability, and hybrid models blending in-person and technology-mediated experiences to inform scalable program design. Fourth, scaling strategy research documenting successful expansion from pilot to system-level implementation remains scarce, requiring dedicated research attention to understand mechanisms enabling effective green skills integration at scale, including policy frameworks, resource allocation models, professional development infrastructure, and quality assurance systems.

3.2.5. Theme Validation Through Dual-Source Integration

The systematic literature and network analysis methodology enabled explicit theme validation through comparison of systematic review findings with bibliometric landscape patterns. Three themes demonstrated convergent high-confidence evidence through dual-source validation. Teacher capacity challenges appeared as the most frequently cited implementation barrier across systematic studies while simultaneously emerging as the newest bibliometric cluster, indicating both practitioner-documented challenges and intensifying scholarly attention. Pedagogical approaches theme validation occurred through systematic evidence documenting experiential learning effectiveness alongside bibliometric prominence of Learning Approaches cluster with transformative learning and experiential learning as core keywords. Holistic framework requirements validated through systematic review documentation of comprehensive approach superiority alongside bibliometric evidence of Sustainability Integration cluster dominance representing the largest thematic domain in the research landscape. Two themes revealed divergent patterns suggesting complementary insights: climate change integration appeared prominently in bibliometric analysis yet received limited attention in systematic review studies, indicating emerging scholarly interest outpacing implementation evidence, while assessment evolution toward behavioral competency appeared as systematic review

theme yet represented newest bibliometric cluster, suggesting implementation practice advancing ahead of scholarly discourse.

3.2.6. Strengths and Limitations

This study's primary strength lies in the integrated SLNA methodology combining systematic review depth with bibliometric analysis breadth to generate comprehensive landscape characterization. The dual-method approach enabled theme validation strengthening confidence in convergent findings while identifying divergent patterns revealing complementary insights from each methodology. The systematic component's geographic and methodological diversity across eleven studies spanning nine countries and multiple research designs strengthens transferability of findings across vocational contexts. The bibliometric component's large sample (314 publications) and temporal analysis (2022-2025) provides robust characterization of research evolution and emerging themes. Several limitations warrant consideration in findings interpretation. First, the single-database search strategy (Scopus only) may have missed relevant publications indexed in other databases such as Web of Science, ERIC, or regional databases covering non-English scholarship. Second, the English-language restriction excludes potentially valuable scholarship from non-Anglophone contexts, particularly relevant given green skills education prominence in Asian and Latin American vocational systems. Third, the recent publication concentration (2024-2025) reflects current research activity but limits historical perspective on field development. Fourth, the small final sample of eleven studies in systematic review component limits subgroup analysis capacity. Fifth, single-reviewer screening and quality assessment introduces potential selection and interpretation bias, representing a methodological limitation warranting careful consideration. While dual-reviewer approaches with inter-rater reliability assessment represent gold-standard practice in systematic review methodology (Page et al., 2021), resource constraints necessitated single-reviewer implementation in this study. Several mitigation strategies were employed to minimize bias risk: explicit inclusion and exclusion criteria were developed a priori and applied consistently throughout screening; comprehensive documentation of exclusion rationales for each eliminated study enabled transparent decision audit trails; standardized data extraction templates with predefined fields reduced interpretive variability; and systematic quality assessment using validated instruments (CASP, MMAT) with documented scoring rationales enhanced assessment consistency. Nevertheless, the absence of independent verification through secondary reviewer screening or third-party auditing means that subjective judgment in borderline cases may have influenced study selection. Future replications employing dual-reviewer protocols with formal inter-rater reliability calculation would strengthen confidence in selection decisions. Researchers interpreting these findings should consider this limitation when evaluating the comprehensiveness of the evidence synthesis, particularly for studies near eligibility thresholds.

4. CONCLUSION

This systematic literature and network analysis provides comprehensive characterization of green skills research in vocational education, revealing both implementation evidence and broader landscape patterns essential for evidence-based practice and research advancement. The integration of systematic review and bibliometric analysis methodologies generates insights unattainable through either approach alone, demonstrating the value of SLNA methodology for educational research synthesis in emerging domains. For VET practitioners and curriculum developers, effective green skills integration requires holistic frameworks implemented through build-in curriculum strategies, extensive instructor professional development address ing content knowledge and pedagogical skills, and strategic industry partnerships enabling authentic experiential learning. The evidence strongly indicates that isolated interventions and inadequately supported implementation achieve limited impact, while comprehensive approaches supported by sustained capacity building demonstrate transformative potential. For researchers, priority directions include longitudinal behavioral outcome assessment tracking workplace sustainability practice adoption, climate change-specific competency framework development, and technology integration evaluation for scalable experiential learning. The convergent evidence gaps identified through integrated analysis represent high-leverage research investment opportunities where new scholarship would substantially advance field understanding and practice effectiveness. The teacher capacity bottleneck documented across studies indicates policy intervention in educator preparation and support represents high-leverage investment opportunity, as inadequate instructor capacity constrains even well-designed curriculum initiatives. The SLNA methodology employed in this study demonstrates significant potential for broader application in educational research, particularly in emerging domains where both micro-level implementation evidence and macro-level landscape understanding inform stakeholder needs.

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