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TVET-SUPPLY DRIVEN INNOVATIONS IN NON-MOTORISED TRANSPORTATION FOR SUSTAINABLE MOBILITY IN AFRICA: A FORESIGHT STRUCTURED LITERATURE REVIEW

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ABSTRACT

This study examines the transformative role of Technical and Vocational Education and Training (TVET) in promoting non-motorised transportation (NMT) as a pathway to sustainable mobility in Africa. A structured literature review was conducted, synthesising 68 peer-reviewed publications from 2010 to 2023 using Scopus and Web of Science databases. Thematic analysis was employed to identify and categorise core trends linking TVET innovations to sustainable transport outcomes. The findings reveal that TVET institutions contribute significantly to the development of context-specific frugal innovations, such as solar-powered bicycles, cargo tricycles, and modular repair kits designed for informal and peri-urban African settings. Despite this potential, TVET-driven innovations remain underrepresented in national transportation policies and urban planning frameworks. This study argues for a stronger alignment between TVET curricula and green mobility policy, supported by skills development in digital fabrication, green energy systems, and local-material engineering. This study also critiques the fragmented application of Industry 4.0/5.0 concepts in the literature and calls for clearer integration frameworks that reflect Africa's technological realities. This review advances a conceptual agenda for leveraging TVET as a catalyst for inclusive low-carbon transport in Africa.

Keywords: *TVET, non-motorised transportation, sustainable mobility, Africa, structured literature review*

1. INTRODUCTION

The growing interest in urban mobility, particularly in the Global South, underscores the urgent need for equitable and sustainable transport solutions tailored to densely populated and rapidly urbanising regions. This mounting interest is driven not only by demographic shifts but also by the intersecting crises of climate vulnerability, outdated infrastructure, and socioeconomic exclusion, particularly for youth and informal workers [1], [2]. This context has emerged against a backdrop of escalating climate change pressures, infrastructure gaps, and the need for inclusive, low-carbon transportation systems. In this context, non-motorised transportation (NMT), such as walking, cycling, and low-emission delivery mechanisms, has gained prominence as a central component of sustainable urban mobility. Rapid urbanisation among commuters, infrastructure shortages, and high unemployment among youth and informal workers provide both challenges and possibilities for including technical and vocational education and training (TVET) into more general sustainability strategies [3], [4].

Integrating TVET into broader sustainability and mobility agendas requires a holistic and interdisciplinary approach involving collaboration among multiple stakeholders across the education, transport, industry, and policy sectors [5]. As transport systems evolve toward environmentally friendly and socially equitable models, the potential role of TVET in supporting skill development for green mobility, explicitly through walking, cycling, and clean delivery systems, has garnered increasing attention in sub-Saharan Africa [6].

Despite policy-level support for sustainability in education systems, the integration of green skills, digital mobility innovations, and NMT competencies into African TVET curricula remains fragmented and underexplored [7], [8]. While frameworks such as the Shanghai Consensus and UNESCO's Green TVET Agenda advocate TVET as a driver of sustainable development [9], the literature indicates that the actual implementation of these concepts in African institutions is inconsistent, often bound by delicate sectoral linkages, outdated training models, and underfunded reform initiatives [10], [11].

Empirical evidence is still limited in explaining how TVET can effectively drive innovation in NMT infrastructure, foster industry-academia partnerships, or facilitate inclusive commuter-oriented design and planning [12], [13]. The key research question guiding this evaluation is: *To what degree are African TVET systems arming students with the skills and information required to enable sustainable non-motorised urban transport and mobility innovation?* This question grounds the review's theoretical orientation and directs its thematic synthesis of African settings.

The review uses three main theoretical frameworks to offer a conceptual basis for looking at this subject. Particularly for green and future-oriented sectors, Human Capital Theory [14], [15] provides a basic perspective by framing TVET as an investment in productivity-enhancing skills [16], [17]. Then, in the framework of new mobility technologies (NMT) and sustainable transportation [18], the Triple Helix Model is investigated to determine how cooperation among government, industry, and academia guarantees curriculum relevance and encourages innovation.

Finally, the TVET–Climate Nexus presents vocational education not only as a tool for the labour market but also as a strategic platform for promoting environmental literacy, low-carbon economies, and community-level resilience [19], [20], [21].

Methodologically, this study adopts a structured narrative literature review, incorporating peer-reviewed articles accessed from the Scopus and Web of Science databases. The inclusion criteria focused on relevance to African urban mobility by analysing peer-reviewed empirical and conceptual works published between 2010 and 2024 across five interrelated thematic domains. This method provides a roadmap for identifying knowledge gaps, implementation weaknesses, and evolving innovations at the interface between TVET and sustainable transport.

By synthesising the current literature across five thematic areas, this structured review not only highlights research gaps and barriers but also provides actionable insights for curriculum developers, policymakers, and industry stakeholders committed to sustainable transport transformation in Africa. This investigation aims to conduct a structured review of existing empirical and conceptual literature that explores how TVET contributes to non-motorised and sustainable transport systems in Africa. This review synthesises developing trends across five key thematic areas: (1) TVET's contribution to sustainable mobility; (2) the role of NMT in climate adaptation and urban planning; (3) TVET reform and technological advancement in sustainable development; (4) industry-academia collaboration for Industry 4.0/5.0 skill development; and (5) repositioning TVET curricula for industrialisation, employability, and contextual relevance in Africa.

Through this synthesis, the review contributes to a sharper understanding of how TVET anchors Africa's transition toward low-carbon, equitable, and inclusive transport futures. It also interrogates the use of terms such as Industry 4.0/5.0 as frameworks that offer structure to the competencies required in modern and future mobility ecosystems. Specifically, Industry 4.0 refers to digital automation, smart infrastructure, and cyber-physical systems in production and logistics, whereas Industry 5.0 emphasises human-centric, sustainable, and resilient design. In the African TVET context, aligning curricula with both paradigms ensures that learners

are not only technologically literate but also equipped to address socio-environmental challenges through innovative approaches.

2. METHODS AND MATERIALS

2.1. Article Selection

To investigate the evolving role of Technical and Vocational Education and Training (TVET) in advancing non-motorised transportation (NMT), sustainable mobility, and green innovation in Africa, this study adopted a structured narrative literature review guided by transparent and replicable selection procedures. A comprehensive search was conducted across top academic databases, including Scopus, Web of Science, and Google Scholar, to map the landscape of scholarly engagement at the intersection of TVET, sustainability, urban transport innovation, and industrial digital transformation.

Rather than employing a formal systematic review protocol, this approach emphasises rigour in screening and synthesis while allowing flexibility to capture interdisciplinary themes relevant to African urban contexts. The objective was to represent a wide variety of empirical methods, conceptual models, and geographic cases that speak to the alignment of TVET with sustainable transport innovation in sub-Saharan Africa and beyond.

The initial search applied a Boolean combination of the targeted keywords.

("Technical and Vocational Education and Training" OR "TVET" OR "Vocational education") AND ("sustainability" OR "green skills" OR "climate adaptation") AND ("mobility" OR "industry collaboration" OR "digital skills")

This yielded over 2,000 articles in the initial search. Inclusion was limited to English-language peer-reviewed journal articles published between 2010 and 2024, consistent with quality assurance and the thematic focus of this review**.** Editorials, policy briefs, book reviews, and non-academic content were excluded.

Eligibility was determined through a three-phase filtering process: (1) de-duplication, (2) abstract screening for thematic relevance to TVET and sustainable transport outcomes (particularly NMT), and (3) full-text review for methodological rigour and contextual alignment. After this process, 110 articles met the preliminary criteria and were subjected to in-depth analysis.

To ensure thematic balance and regional inclusivity, the resulting dataset was organised by both topical domain and geographic focus, emphasising the African context, where applicable. The final dataset consisted of 45 articles that explicitly addressed one or more core themes, including TVET and sustainability, Industry

4.0/5.0 preparedness, informal urban transport innovations, and curriculum alignment with climate adaptation and mobility technologies.

2.2. Review Structure and Thematic Synthesis

Following article selection, a structured thematic synthesis was performed to classify, compare, and interpret the findings according to the review objectives. Thematic coding was guided by five predefined domains derived from literature trends, policy frameworks and theoretical anchors:

1. TVET's contribution to sustainable mobility, focusing on low-carbon and inclusive transport skills
2. The role of non-motorised transport (NMT) in urban planning and climate resilience strategies.
3. TVET reform and the integration of digital and environmental technologies, including Industry 4.0 and 5.0.
4. Industry-academia collaboration for competency-based and future-ready skills development.
5. Curriculum repositioning for African industrialisation, employment and local relevance.

Each article was reviewed in full and analysed based on a consistent matrix of four analytical dimensions: topic focus, regional scope, theoretical orientation, and methodological approaches. This matrix facilitated pattern recognition, cross-theme triangulation, and the identification of empirical, conceptual, and policy gaps. Although no automated coding software was used, internal validity was enhanced through manual cross-checking, iterative categorisation, and validation of the article-to-theme fit. This ensured coherence in theme allocation and minimised selection bias.

Special attention was given to studies linking TVET initiatives to tangible transport innovations such as cycling infrastructure, solar-powered logistics, digital mobility planning, and vocational skill hubs in informal settlements. These intersections were mapped to evaluate policy discourse, curriculum responsiveness, and institutional innovation across different African countries.

Table 1 presents a synthesis matrix that summarises how the articles were categorised, the content addressed, and the rationale for their inclusion. This classification framework provides transparency and replicability, aligning the reviewed studies with the thematic pillars of the investigation.

Table 1: Thematic synthesis classification framework summarising categorisation, addressed content, and inclusion justification across key review themes

Categorisation	Content Addressed	Inclusion Justification
TVET and sustainable mobility	Mobility TVET's promotion of accessible mobility, walking, cycling, and green transportation	Coordinates with SDGs 11 and 13; **emphasises skill development for climate-resilient transport solutions**
Non-Motorised Transportation (NMT)	Urban design, cyclist/pedestrian infrastructure, spatial equity	Fills knowledge gap on low-carbon mobility systems and their social integration in African urban environments
TVET Reform and Integration of Technology	Digital skills, curriculum innovation, Industry 4.0/5.0 preparedness	Responds to the demand for **TVET modernisation aligned with digital and ecological transformation trends**
Industry-Academia Cooperation	Public-private agreements, internships, co-designed courses	Supports the development of industry-relevant and experiential training frameworks
Repositioning Contextual Curriculum	Indigenous knowledge, business, heritage-based invention	Contributes to curriculum decolonisation, cultural relevance, and place-based industrial policy alignment

3. RESULTS

3.1. Contribution of TVET Towards Sustainable Mobility

Global attention to non-motorised transportation (NMT) and sustainable mobility solutions has intensified owing to the urgent need for climate action and the creation of low-carbon urban systems. Within this context, Technical and Vocational Education and Training (TVET) is increasingly positioned as a critical enabler of green transport transitions, especially by equipping the workforce with specialised skills in areas such as bicycle repair, green logistics, and solar mobility systems.

TVET's role extends beyond traditional skill delivery; it cultivates sustainability values, encourages frugal transport innovation, and enables inclusive participation in emerging green economies. The literature consistently highlights the urgency of aligning TVET curricula with the practical requirements of sustainable mobility, especially in Sub-Saharan Africa, where rapid urbanisation, infrastructure deficits, and youth unemployment intersect.

A pivotal study by [9] emphasises the importance of embedding circular economy and environmental content within TVET programmes, citing global efforts such as the Shanghai Consensus. However, despite evident policy-level momentum, implementation across African contexts remains fragmented. As shown by [22], most of the circular economy and green skill initiatives are concentrated in high-income regions, revealing persistent inequities in the localisation of sustainability education in African TVET systems.

Building on this, [23] advocated the reorientation of African TVET curricula toward Industry 4.0 applications, including smart infrastructure and electric mobility. Their future-focused model proposes digital and systems-based training approaches to prepare students for intelligent transportation systems. However, they also acknowledge the institutional inertia within many African colleges, which continue to operate outdated curricula misaligned with sectoral needs.

In a socio-economic case study from Samoa, [24] demonstrated that TVET-trained individuals positively influence local mobility outcomes by contributing to community infrastructure. Although not NMT-specific, this study suggests a grassroots impact pathway for TVET in transport innovation. Similarly, [25] argues that TVET institutions play a pivotal role in UNESCO's "Learning Cities" initiative by facilitating inclusive mobility planning, particularly for women, informal workers, and marginalised groups.

Despite these promising frameworks, empirical evidence directly linking TVET to NMT system development, such as walking paths, cycling infrastructure, or solar-powered micro-mobility, remains sparse. Few initiatives have tested TVET pedagogy using active learning tools or participatory design frameworks. As [26] shows, even when digital simulations are employed to train sustainable transport thinking, their uptake in African institutions is limited.

Weak institutional coordination, limited transport sector collaboration, and a lack of performance monitoring are major barriers to scaling TVET-led NMT innovations. Furthermore, although women disproportionately rely on NMT in African cities, the gender lens in TVET mobility training is grossly underdeveloped in Africa.

In summary, the literature confirms TVET's strategic importance in advancing low-carbon and inclusive urban mobility. However, this contribution remains conceptual, policy-driven, and inconsistently implemented in Africa. Persistent gaps in curriculum alignment, digital adaptation, institutional capacity, and sector integration underscore the need for reform. These findings reinforce the rationale of this review in empirically mapping how TVET systems across Africa can support sustainable

mobility transitions through NMT innovation, localised training, and inclusive access.

3.2. The Contribution of Non-Motorised Transportation (NMT) in Urban Planning and Climate Change Adaptation

Contemporary strategies for climate-resilient urban development increasingly prioritise non-motorised transportation (NMT), commonly categorised as active transport modes, such as walkability, cycling, and emerging micromobility solutions like e-scooters and cargo bikes. NMT serves as an affordable, low-emission mobility option and enhances urban inclusivity, public health, and environmental equity. As African cities face mounting pressures from air pollution, traffic congestion, and infrastructure gaps, NMT is being redefined in the literature as a dual-function solution, both as a mitigator of emissions and an adaptive urban planning response to climate instability.

Studies by [27] and [28] emphasised the pivotal role of spatial planning and land-use regulation in institutionalising NMT within urban mobility frameworks. Using advanced analytical tools such as fuzzy set theory, geospatial modelling, and accessibility indices, these studies reveal how urban form compactness, service density, and land-use integration correlate with active mobility uptake. However, in Sub-Saharan African cities, spatial planning tends to be fragmented, with NMT infrastructure often relegated to informal corridors or underserved peripheries that lack policy support and budgetary allocation. This restricts the potential of NMT to contribute to equitable access and climate resilience in the region.

Equally critical is the behavioural dimension of NMT adoption, which remains understudied in Africa. Empirical studies from Indian cities, including [29] and [30], demonstrate that although public openness to walking and cycling exists, uptake is significantly hindered by poor infrastructure, safety risks, and inadequate connectivity. These insights underline the importance of behavioural mapping, user perception studies, and human-centred design in planning NMT systems. African cities face similar challenges but lack region-specific behavioural datasets, limiting comparative policy learning and context-tailored interventions.

The key topics dominating NMT research include infrastructure quality, route attractiveness, and physical accessibility. Through GIS-based decision models, [31] identified factors such as surface texture, intersection frequency, and traffic volume as critical determinants of bicycle route choice. Applying the Three-Factor Theory, [32] showed that socio-demographic variables such as age and gender affect pedestrian satisfaction. Nonetheless, most of these analyses are skewed toward Asian and European contexts, with minimal empirical validation in African cities, where

informal transport, weak enforcement, and infrastructure deficits complicate formal NMT adoption.

Smart mobility frameworks are beginning to influence the NMT. Artificial intelligence (AI), Internet of Things (IoT), and real-time ICT tools are being utilised to optimise pedestrian and cycling infrastructure, improve safety surveillance, and link mobility data to broader urban analytics. For instance, [33] proposed a Smart Active Mobility (SAM) model to enhance active transport planning. However, in African cities, the digital infrastructure needed to operationalise such models remains inadequate, and there is scant research on user interaction with digital NMT tools, raising concerns about technological inclusion, accessibility, and readiness in this context.

Ultimately, the institutional ecosystem plays a decisive role in the mainstreaming of NMT. Using a systems dynamics approach, [33] demonstrated how coherent policies, clear regulatory mandates, and inter-agency coordination drive public buy-in and resource allocation for NMT. In contrast, [30] shows that even with infrastructure investment, poor implementation and weak stakeholder engagement can stall progress. This governance gap is especially acute in sub-Saharan Africa, where transport institutions are often under-resourced, donor-reliant, and siloed, lacking the capacity for long-term NMT strategy execution or monitoring.

In conclusion, the reviewed literature affirms that NMT has transformative potential for enabling climate adaptation, promoting low-carbon urban mobility, and achieving spatial justice. However, African contexts remain underexplored in terms of empirical analyses, policy experimentation, and technological adaptation. To unlock NMT's full value, future research must prioritise behavioural insights, implementation-focused governance studies, and scalable models tailored to low-income, infrastructure-limited settings. Such efforts will bridge the implementation gap and embed NMT as a viable pillar of Africa’s sustainable urban transition.

3.3. Technological Advancement and Reforms for Sustainable Development in TVET

In the Global South, reforming Technical and Vocational Education and Training (TVET) systems has become strategically important in the quest for sustainable development and climate resilience. Three interrelated imperatives–enhancing systemic quality, embedding environmental sustainability, and mainstreaming emerging technologies such as artificial intelligence (AI), robotics, and the Internet of Things (IoT)–now define the transformation trajectory of TVET institutions. The literature confirms that TVET must be realigned through comprehensive reform agendas encompassing institutional governance, outcome-oriented curriculum

design, technological adaptation, and social inclusion to meaningfully support green economies and a resilient future.

Tracking a ten-year trajectory of regional devolution, private sector involvement, and ICT integration [34] offers one of the most thorough empirical studies on TVET reform in China. The analysis shows that targeted investments in decentralised institutions and multi-stakeholder coordination mechanisms substantially increase responsiveness to evolving labour market demands, especially in green infrastructure and intelligent transportation. Although this approach presents a robust reform blueprint, its contextual transferability to African settings is constrained by structural challenges, including financing gaps, bureaucratic inefficiencies, and capacity mismatches.

From a regional African perspective, [23] contend that systems thinking, digital literacy, and industry-aligned training must be central to future-oriented TVET reform. Their study highlights the skills mismatch between current TVET offerings and the rapidly evolving competencies required in sectors such as mobility electrification, data-driven logistics, and circular manufacturing. They advocate for a redesigned competency-based education (CBE) framework informed by Industry 4.0 principles, though they acknowledge that implementation barriers, particularly in terms of trainer readiness and institutional digital infrastructure, remain significant.

Technological integration in TVET remains uneven across regions, particularly in resource-constrained settings. In a systematic review, [35] highlighted disparities in the deployment of digital tools such as AI-assisted learning platforms, cloud-based simulation software, and mobile-accessible e-learning modules. Pilot projects suggest the potential of these tools to enhance learning personalisation and expand access; however, scalability is hampered by poor broadband coverage, digital exclusion, and weak policy coordination. In sub-Saharan Africa, the digital divide between urban and rural training centres remains a persistent equity barrier.

TVET reform's contribution to sustainability also hinges on curriculum re-engineering to embed green competencies, climate literacy, and circular economy concepts. [9] emphasises that, beyond technical know-how, students must be trained in environmental stewardship, energy efficiency, and life cycle thinking. While some national reforms signal the intent to integrate such elements, the actual operationalisation of sustainability modules is limited by inadequate instructional resources, fragmented policy ownership, and a lack of competency-based sustainability benchmarks.

Governance challenges continue to constrain the effectiveness of reforms. As [36] notes, in the case of India, fragmented mandates, donor-driven agendas, and poor

stakeholder alignment have undermined long-term change. Similar dynamics are evident in many African countries, where accountability structures are weak, inter-agency cooperation is minimal, and performance measurement systems are underdeveloped. Consequently, despite the proliferation of reform strategies, systemic inertia and limited implementation capacity dilute their impacts. Meaningful transformation requires not only technical upgrades but also political commitment, multistakeholder engagement, and coherent institutional frameworks.

In conclusion, the literature affirms that TVET reforms anchored in digital innovation and green skills development are essential for achieving sustainability goals. However, the uneven implementation across African contexts underscores the urgency of locally grounded, evidence-based strategies. Future research should prioritise empirical assessments of TVET implementation, digital infrastructure investment, and sustainability-linked learning outcomes. This would enable a more robust integration of TVET systems into national climate strategies and inclusive development agendas in the future.

3.4. Industry-Academic Collaboration for Industry 4.0 and Industry 5.0 Skills Development

The transition toward digitally integrated and environmentally responsive economies has significantly increased the demand for workforce competencies aligned with both Industry 4.0 and the more inclusive, human-centred Industry 5.0 paradigms. In this evolving framework, collaboration between industry and academic institutions, particularly within TVET ecosystems, has become essential to address the persistent mismatch between labour market needs and educational outputs. These partnerships not only support the technological upgrading of curricula but also enable practical exposure that directly influences innovations in green and sustainable transport, including last-mile logistics, NMT infrastructure, and solar mobility systems.

Well-structured cooperation involving colleges, technical institutions, and businesses helps ensure curriculum responsiveness, embeds experiential learning modules, promotes innovation, and facilitates smoother transitions from the classroom to real-world applications, particularly in areas relevant to sustainable mobility. The reviewed literature suggests that establishing future-ready workforces requires co-created, work-integrated, and socially aligned training approaches that are responsive to both technological advancement and sustainability mandates.

[37] advocates modular, industry-driven courses that reduce the theory-practice divide and improve employability. However, despite favourable policies, most low- and middle-income countries lack robust institutional frameworks for their sustained implementation. This shortfall is especially limiting in African TVET systems, where

the integration of green transport curricula, such as solar vehicle repair, cycling infrastructure planning, and digital mobility analytics, remains minimal.

Evidence from [38] highlights the benefits of early-stage industry-sponsored capstone projects and mentorship. This significantly improves learner engagement, especially in automation and transport-related fields, where hands-on experience is critical. Nevertheless, many institutions, particularly in Africa, face barriers such as rigid calendars, limited placement capacity, and insufficient industry preparedness to absorb interns into their organisations.

Industry 5.0 introduces new imperatives, such as ethics, inclusion, and human-machine symbiosis, that demand a rethink of how academic curricula are designed. [39] underscores the need for universities to balance automation demands with inclusion and environmental justice. This includes integrating concepts such as ethical AI, green robotics, and system-based mobility diagnostics into TVET pedagogy. [40] emphasises that faculty retraining and institutional reform are necessary to facilitate these transitions. However, most existing collaborations operate within the logic of Industry 4.0, with limited adaptation to the ideals of Industry 5.0.

Work-integrated learning (WIL) has emerged as a core mechanism for embedding real-world experiences into TVET programs. The Ethiopian case studied by [41] demonstrates the success of jointly developed curricula between TVET colleges and manufacturing firms that incorporate aligned evaluation tools and mentorship schemes. However, these efforts often lack scalability because of policy fragmentation and weak monitoring mechanisms.

Moreover, collaboration models remain largely exclusive to micro, small, and medium-sized enterprises (MSMEs), despite their outsized role in informal and localised mobility innovations. [42] argues that although MSMEs are strategic actors in areas such as cycle logistics and artisanal transport tools, they are often excluded from formal partnerships because of informality, digital barriers, and limited institutional reach.

Robust governance and regulatory coherence are essential for scaling up and stabilising industry-academic linkages. [43] notes that mutual investments in infrastructure, co-developed performance metrics and accountability frameworks enhance partnership credibility. [44] recommends innovation clusters and regional hubs as platforms for continuous engagement. [45] points to COVID-19 as a stress test for partnership resilience, with many initiatives faltering due to weak institutional backup.

In summary, the literature shows that while industry-academia collaboration is pivotal for TVET transformation, its contribution to sustainable transport ecosystems, particularly in African contexts, is underdeveloped. Future models must prioritise the integration of Industry 5.0 principles, MSME inclusion, and policy institutionalisation to achieve both employment outcomes and climate-aligned transport solutions.

3.5. Stabilising TVET Curriculum for Contextual Relevance, Employability, and Industrialisation in Africa

Curriculum design within Technical and Vocational Education and Training (TVET) systems is gaining renewed importance across African nations amid the growing demand for inclusive industrialisation, green transitions, and employment-driven mobility solutions. A well-positioned TVET curriculum must not only meet immediate labour market needs but also cultivate adaptive, sustainability-literate, and context-responsive competencies relevant to national priorities and local livelihoods.

Despite policy reforms advocating for modernisation, a persistent gap exists between the stated curriculum objectives and the practical realities of training delivery. Many initiatives lack mechanisms to align curricular content with sector-specific demands, particularly in transport infrastructure, clean logistics, and decentralised mobility services, which are critical to climate-resilient development.

In Kenya, [11] identified a disconnect between TVET course content and the skill requirements of sectors such as construction and mechanical engineering, where mobility technologies and sustainable infrastructure are becoming increasingly important. Graduates often lack practical proficiency, while competency-based education frameworks struggle due to insufficient faculty training, poorly designed assessments, and limited employer engagement.

Similarly, [46] documented curriculum limitations in South Africa's National Certificate Vocational (NCV) system. While intended to produce job-ready graduates, the system is hampered by obsolete training infrastructure, weak exposure to practical tasks, and inadequate private-sector linkages. These findings underscore the urgency of modernising TVET programmes to accommodate emerging transport technologies, digital diagnostics, and climate-smart practices.

[47] advocated for a heritage-based and decolonised TVET curriculum in Zimbabwe, emphasising indigenous knowledge, the use of local materials, and entrepreneurship as avenues for inclusive industrial transformation. This approach, anchored in local value chains and informal mobility innovation, seeks to reposition graduates as inventors rather than mere job seekers. Although underexplored at scale, this

philosophy aligns with the African Union's Agenda 2063, which prioritises home-grown innovation and sustainable livelihoods.

In Egypt, [48] examined large-scale reforms that integrated demand-responsive curricula aligned with national development plans to improve youth employability in strategic sectors. However, these successes depend on robust monitoring systems that track labour market dynamics and enable effective public-private collaboration, a feature that is still underdeveloped in most sub-Saharan countries.

Beyond content, systemic barriers such as economic informality, weak governance, and fragmented oversight structures continue to impair the effectiveness of the curriculum. [49] argues that poor TVET outcomes in Sub-Saharan Africa often stem not from curriculum design flaws but from low absorption capacity in the labour market, societal bias toward academic tracks, and the imposition of externally borrowed models without contextual adaptation. The absence of evaluation mechanisms and limited business engagement in course validation further undermines efforts to deliver impactful and relevant training.

Emerging curriculum priorities now include the integration of sustainability, green technologies, and entrepreneurial skills, in line with the Sustainable Development Goals. [9] emphasises the importance of embedding environmental awareness, life-cycle thinking, and low-carbon innovation into technical education. However, [50] notes that donor-driven reforms often lack longevity, scalability, and empirical validation, making curriculum reform sporadic and uneven across the continent.

Regional platforms, such as the Regional Association of Vocational and Technical Education (RAVTE), are underutilised as hubs for peer learning and curriculum co-development. Strengthening such networks can foster cross-country knowledge transfer, especially in climate-resilient transport systems, solar-powered mobility solutions, and circular economy skills areas where TVET can demonstrate a high local impact.

In conclusion, the literature confirms the urgency of positioning African TVET systems as catalysts for industrial transition and sustainable employment, especially in the mobility and green infrastructure sectors. While frameworks and reform agendas exist, their translation into localised, employer-validated, and forward-looking curricula remains inconsistent and fragmented. Addressing these shortcomings demands evidence-driven strategies that link training to industry needs, enhance local content, and build institutional capacity to adapt to evolving development priorities, including low-carbon transportation innovation.

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4. DISCUSSION

This structured review investigates how Technical and Vocational Education and Training (TVET) systems in Africa contribute to sustainable urban mobility, with particular emphasis on non-motorised transport (NMT), green skills acquisition, and inclusive infrastructure planning. Across the five thematic strands analysed, the findings reveal that TVET plays an emerging role in bridging the skills gap in sectors such as climate-resilient transportation, last-mile logistics, and renewable energy-driven mobility systems. However, aligning technical training programs with broader development goals, including climate adaptation, just urban transitions, and industrial innovation, remains challenging due to systemic limitations such as fragmented governance, limited industry engagement, and outdated curricular models in many African contexts.

The analysis is anchored in three interrelated conceptual frameworks. Human Capital Theory positions TVET as a long-term investment in national productivity and workforce sustainability. The Triple Helix Model emphasises the necessity of coordinated engagement among government, industry, and academia to foster innovation ecosystems. The TVET–Climate Nexus, an emerging paradigm, illustrates how vocational education can act as a conduit for ecological literacy, low-carbon technology diffusion, and localised resilience building in African cities. Together, these frameworks provide an integrated lens for understanding how TVET can be repositioned not only as a workforce pipeline but also as a strategic instrument for achieving inclusive, digitally enabled, and climate-aligned mobility transitions in the Global South.

4.1. Synopsis of Cross-Cutting Realisations

The reviewed literature positions Technical and Vocational Education and Training (TVET) as a strategic enabler of localised, low-carbon transport systems, particularly through its contribution to environmental literacy, green job skills, and participatory infrastructure development. Beyond its traditional role in workforce preparation, TVET is increasingly recognised as a platform for advancing environmental stewardship, social inclusion, and climate-adaptive mobility.

These roles align with the Human Capital Theory, which views education as a public investment in enhancing human productivity and societal well-being. Within the context of sustainable transport, this translates into cultivating skills for electric bicycle maintenance, solar mobility deployment, and community-based cycling networks, areas where TVET institutions can directly influence inclusive mobility access in African cities.

The review further highlights how curriculum reforms that incorporate digital competencies, Industry 4.0 technologies, and systems thinking are reshaping the TVET landscape. Such reforms facilitate readiness for smart transport infrastructure, automated logistics, and intelligent mobility services, which are key pillars of emerging urban economies.

This shift is reinforced by the Triple Helix Model, which emphasises collaborative governance among academia, industry, and government. In TVET systems, this is evident through co-designed curricula, mentoring by transport sector professionals, and structured industry placements, particularly in mobility-related sectors such as last-mile delivery and sustainable logistics.

Recent contributions [47] advocate for heritage-based and decolonised TVET pedagogies that centre Indigenous knowledge, localised value chains, and culturally relevant skill sets. These approaches enable TVET institutions to serve not only formal job markets but also informal economies, where micro-mobility innovation and repair services thrive, especially in underserved or peri-urban African areas.

4.2. Gaps, Paradoxes, and Understudied Dimensions

Despite the growing scholarly interest in the intersection of Technical and Vocational Education and Training (TVET) and sustainable mobility, significant empirical and theoretical gaps remain. Notably, there is a scarcity of research that explicitly connects TVET to the design, construction, and maintenance of non-motorised transport (NMT) infrastructure, such as walking paths, cycling lanes, solar-powered logistics hubs, and micro-mobility services in African cities [33].

Many studies present inclusive mobility as a normative goal but fall short of articulating the concrete pedagogical tools, course modules, or skill-development strategies needed to realise it through TVET curricula. This undermines the potential to operationalise TVET as a delivery mechanism for sustainable transportation outcomes.

The global distribution of literature also reveals a geographic research imbalance, with most empirical evidence concentrated in Southeast Asia and Latin America, where TVET reforms have successfully integrated green and digital skillsets. For example, China's coordinated national approach to green infrastructure skills through TVET [34] provides a model that can be replicated. In contrast, Sub-Saharan Africa lacks systematic documentation, coordinated policy support, and urban mobility-aligned training pathways, limiting the ability of researchers and policymakers to adapt successful models to African realities, particularly those affecting women, youth, and informal workers.

A major conceptual paradox lies in the rhetorical embrace of Industry 5.0 values, such as inclusivity, ethical design, and human-machine collaboration, within African policy frameworks, while most institutional practices remain grounded in Industry 4.0 paradigms focused narrowly on automation and productivity. This misalignment results in limited curricular innovation, inadequate faculty retraining, and a lack of interdisciplinary teaching models that could translate the 5.0 ideals into practice.

Another critical omission is the absence of participatory monitoring and curriculum feedback systems, which restricts iterative improvement and reduces the responsiveness of TVET institutions to evolving labour and sustainability requirements. This is especially problematic in settings where transportation needs and climate vulnerabilities shift rapidly.

Furthermore, there is a lack of standardised assessment tools to measure outcomes such as green skills acquisition, sustainability literacy, and the long-term effectiveness of work-integrated learning (WIL) models. While many studies conclude with policy recommendations, few include empirical validation of implementation, behavioural change, or sectoral impact, limiting both theory development and the evidence base for effective decision-making [13].

4.3. Implications for Theory, Policy and Practice

For African cities to achieve low-carbon and inclusive urban mobility, TVET must be institutionalised as a core component of national sustainability and climate adaptation strategies. This requires embedding green mobility modules, including cycling infrastructure, solar transport systems, and last-mile delivery technologies,

within national certification frameworks. Funding schemes should be aligned to support training infrastructure, curriculum reform, and program scaling across rural and urban regions of the country.

Effective implementation also demands regulatory frameworks that formalise industry-academic partnerships, incentivise participation by micro, small, and medium-sized enterprises (MSMEs), and ensure that TVET initiatives are responsive to real-world transport challenges. Given that women disproportionately depend on non-motorised transport (NMT) modes in African cities [3], gender-inclusive mobility policies and training designs should be prioritised to promote equitable access and participation.

4.3.1. Institutional Implications

TVET institutions and training providers should develop modular, locally adaptable programs focused on priority areas, such as green logistics, e-bike and solar vehicle maintenance, digital mapping for mobility, and intelligent transport systems (ITS). These courses must be pilot-tested in collaboration with local governments and urban transit authorities to ensure their relevance, scalability, and community ownership. Additionally, targeted investments are required in digital laboratories, instructor retraining, and real-time outcome tracking systems to assess the impact and inform continuous curriculum refinement.

4.3.2. Theoretical Implications

The evolving role of TVET in sustainable mobility demands a multi-theoretical lens that integrates Human Capital Theory (HCT), Sustainability Transitions Theory, the TVET–Climate Nexus, and the Resource-Based View (RBV). HCT helps situate TVET as an investment in long-term productivity and resilience. Sustainability Transitions Theory enables an analysis of how educational reforms support shifts toward low-carbon infrastructure. The TVET–Climate Nexus foregrounds vocational training as a driver of community adaptation and ecological literacy. RBV provides a framework for assessing how internal institutional capabilities, such as green training resources and digital readiness, can shape competitive advantages in mobility innovation.

Future research should use these frameworks to develop Africa-centred theoretical models based on urban realities, behavioural insights, and grassroots innovation ecosystems. These models should address the dynamic interface between vocational training and transport equity, enabling scholars and practitioners to better understand how TVET can catalyse low-carbon transitions that are both socially inclusive and locally grounded.

The Stakeholder-Oriented Implications Matrix for Strengthening TVET and NMT Integration helps to further synthesise the insights offered and provide actionable guidance for stakeholders, as indicated in Table 2.

Table 2: Stakeholder-oriented actions and outcomes for strengthening TVET and NMT integration toward sustainable urban mobility

Investor	Action	Outcome Impact
Policymakers	Expand coverage of green/NMT knowledge into national TVET systems; encourage MSME collaboration networks	Improved employment and SDG policy congruence
Training Centres	Create pilot NMT training courses and alliances with municipal or transit authorities.	Locally relevant and easily used mobility solutions
Industrial Associations	Create courses in co-design; involve small businesses and supervise interns.	Strengthened sectoral links and innovation capacity
Researchers	Using participative approaches, assess green skill outcomes; publish African NMT case studies.	Regional learning and curriculum development informed by data
Donor Organizations	Back digital infrastructure, capacity building, and monitoring systems.	Sustainable and scalable reform systems

With a focused emphasis on non-motorised transport (NMT) and green skills development, this review synthesises how technical and vocational education and training (TVET) can support sustainable transport transitions in Africa. Drawing on a structured analysis of 45 peer-reviewed studies, the findings confirm that TVET is not only a workforce development mechanism but also a critical enabler of climate adaptation, equitable mobility and local resilience

Framed through an integrated theoretical lens combining Human Capital Theory, the Triple Helix Model, and the TVET–Climate Nexus, this study positions vocational education as a socio-technical platform for advancing low-carbon transport futures. For policymakers, this implies the urgent inclusion of sustainability-oriented mobility modules into national training frameworks. For training institutions, this calls for the development of context-responsive, digitally enabled curricula. For researchers, the findings highlight critical gaps in gender-responsive mobility planning, digital access, and the integration of informal transport actors into green-skills ecosystems.

Future research should prioritise longitudinal, participatory, and cross-urban studies that engage community-based innovations, local knowledge systems and behaviourally informed design. This approach will better capture how TVET can

function as a pillar of inclusive, just, and climate-resilient mobility in Africa, particularly by empowering youth, women, and underserved urban populations through targeted skill development and infrastructural integration.

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