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INDUSTRY 4.0 READINESS OF TVET INSTITUTIONS IN SUB-SAHARAN AFRICA: A COMPARATIVE ASSESSMENT OF CURRICULUM ALIGNMENT, INFRASTRUCTURE, AND INSTRUCTOR COMPETENCIES

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Abstract

The rapid uptake of Industry 4.0 technologies across African manufacturing, agribusiness, and logistics sectors has created an urgent question that TVET systems have been slow to answer: are technical training institutions prepared to produce the kind of graduates that these sectors now require? This article presents findings from a comparative institutional assessment conducted across forty-two TVET institutions in Kenya, Ghana, and Nigeria. The study evaluated readiness across three core dimensions — curriculum alignment with Industry 4.0 competency requirements, physical and digital infrastructure availability, and instructor technical competency in automation and digital production systems. A composite Industry 4.0 Readiness Index was constructed using institutional survey data, a practical instructor skills assessment, classroom observation, and structured interviews with 186 instructors and 312 recent graduates. The mean readiness score across the sample was 31.4 out of 100. Urban flagship institutions averaged 47.2 while rural and community-based colleges averaged just 19.6. Curriculum misalignment is the single largest contributor to the readiness gap, followed by instructor competency deficits and infrastructure shortfalls. The findings indicate that conventional curriculum revision processes are far too slow for the pace of Industry 4.0 change, that instructor retraining needs are significantly underestimated in national TVET plans, and that geographic concentration of adequately resourced institutions is producing a two-tier training system that risks deepening existing inequalities. The paper draws on these findings to offer a set of specific and actionable policy recommendations for TVET authorities, ministries of education, and development partners operating in the Sub-Saharan context.

Keywords: Industry 4.0, TVET readiness, Sub-Saharan Africa, curriculum alignment, instructor competency, skills gap, Kenya, Ghana, Nigeria.

INTRODUCTION

Walk into most TVET workshops in Nairobi, Accra, or Lagos and the scene is not dramatically different from what you would have found twenty years ago. Lathes, welding benches, and sewing machines are still the dominant equipment. Instructors who trained in analogue industrial environments continue teaching the syllabi they inherited. And yet the factories, agriprocessing plants, and logistics firms where many of these graduates end up are quietly installing collaborative robots, cloud-connected quality sensors, and AI-assisted scheduling systems. The gap between what training institutions produce and what industry now demands has not merely widened — it has changed in character.

Industry 4.0 — a term describing the convergence of cyber-physical systems, the Internet of Things, advanced robotics, big data analytics, additive manufacturing, and artificial intelligence into modern industrial production — is no longer a distant prospect for Sub-Saharan Africa (Schwab, 2016; Xu et al., 2018). It is already operating in the factories and processing plants where TVET graduates seek employment. Kenya's flower export sector uses precision climate control and cold-chain monitoring as standard. Nigeria's pharmaceutical industry is rolling out automated dispensing and batch traceability systems. Ghana's cocoa processing companies are piloting sensor-based fermentation management. These are not experimental pilots — they are operational realities that are reshaping the skill requirements of entry-level technical workers right now.

The question this article takes seriously is not whether Industry 4.0 is arriving in Sub-Saharan Africa. It already has. The question is whether the region's TVET institutions are equipped to train workers who can operate, maintain, and improve the systems that this industrial transformation is deploying. To investigate this rigorously, we developed an Industry 4.0 Readiness Index (I4RI) and applied it to forty-two TVET institutions across Kenya, Ghana, and Nigeria — producing what is, to our knowledge, the most geographically and institutionally diverse comparative assessment of this kind yet conducted in the region (Allais, 2020; McGrath, 2018).

The three countries were deliberately chosen to represent different points on the TVET reform spectrum. Kenya has implemented sustained curriculum reform since 2017 under its Competency-Based Education and Training framework and has explicit Industry 4.0 language in its national TVET policy documents (Technical and Vocational Education and Training Authority Kenya, 2022). Ghana undertook a major TVET reclassification in 2016 and has invested significantly in upgrading its technical universities, though implementation at the college level has been inconsistent. Nigeria runs the largest TVET system by enrolment in Sub-Saharan Africa but has struggled with chronic underfunding and infrastructure that in many institutions has not been meaningfully updated in decades (National Board for Technical Education Nigeria, 2021). Together, these three systems offer a representative and instructive picture of the region's challenges.

The article proceeds as follows. Section 2 reviews the relevant literature on Industry 4.0 and TVET in developing country contexts. Section 3 describes the methodology and the construction of the I4RI. Section 4 presents the key findings. Section 5 discusses the findings and draws out their policy implications. Section 6 contains the dedicated policy recommendations. Section 7 concludes.

Literature Review

The Changing Shape of Industrial Skill Requirements

Industry 4.0 has changed the nature of technical work in ways that matter profoundly for how TVET programmes are designed (Acemoglu & Restrepo, 2018; World Economic Forum, 2020). Previous waves of industrial automation primarily displaced routine physical tasks — machine tending, precision assembly, repetitive material handling — while increasing the premium on craft knowledge, manual dexterity, and experienced judgement. That relationship was broadly favourable to TVET. An experienced welder or machinist who had developed fine motor skills through years of practice represented a form of human capital that machines could not easily replicate.

Industry 4.0 disrupts this dynamic. Collaborative robots, CNC systems, and automated inspection equipment reduce the value of manual precision while raising the demand for workers who can programme, monitor, configure, and diagnose these technologies. A machinist who cannot read a G-code programme or interpret a machine alarm log is of substantially less value to a modern production environment than one who can, regardless of how refined their manual technique is (Brynjolfsson & McAfee, 2014; Goos et al., 2014). The skills that now differentiate productive workers in Industry 4.0 environments fall into three broad clusters: digital literacy in both consumer computing and industrial data systems; systems thinking — the capacity to understand how automated components interact and fail; and adaptive problem-solving in situations that cannot be fully anticipated in a training curriculum.

It is worth being precise about what Industry 4.0 readiness means in the Sub-Saharan African context. Technology adoption in African industry is uneven and sector-specific (Banga, 2019). A maize milling cooperative in rural western Kenya faces different demands from a Nairobi electronics assembly plant supplying an export market. TVET readiness assessments that treat "Industry 4.0" as a single uniform requirement risk producing policy recommendations that are well calibrated to the needs of a small number of high-technology urban employers while being largely irrelevant to the much larger number of graduates who will work in less digitally intensive environments. This study's assessment framework was designed with that complexity in mind.

Competency-Based Training and Its Limits in African TVET

Competency-Based Training was adopted by Kenya, Ghana, and several other African countries as the primary mechanism for improving curriculum alignment with labour market requirements (Republic of Kenya, 2013; Mumo & Mwangi, 2021). The logic is straightforward: if training outcomes are defined in terms of competencies that industry has validated, then training will be more relevant to real jobs. In principle, this should make TVET systems more responsive to technological change. In practice, the competency standard revision process has proven too slow, too expensive, and too politically cumbersome to keep pace with Industry 4.0.

Kenya's competency standards, for example, typically require two to four years to move from a needs assessment through stakeholder consultation, validation workshops, and formal gazette. A standard gazetted today describes the technology environment of 2021 or 2022. Given the pace at which industrial automation equipment, software platforms, and data management systems are evolving, a four-year revision cycle produces standards that are obsolescent the moment they are published (Boateng, 2012; Akyeampong, 2010).

Several researchers have documented the gap between the stated intentions of CBT reform and its implementation reality in African TVET institutions. Instructors frequently lack the industry experience needed to deliver competency modules in the spirit they were designed. Assessment instruments tend to test theoretical recall rather than practical competency. And the equipment needed to demonstrate the relevant skills — PLC trainers, CNC workstations, 3D printers, industrial sensors — is either absent or present in only a handful of flagship institutions that serve a small minority of TVET students (Boateng, 2012; Akyeampong, 2010).

Instructor Competency: The Human Side of the Gap

The quality of technical instruction depends on instructors who have current, applied knowledge of what they are teaching (Hanushek, & Woessmann, 2015; Kluve, 2010). This has always been true, but it becomes particularly demanding in the Industry 4.0 context because the relevant knowledge is changing faster than any previous phase of industrial development. An instructor who completed a credible digital fabrication programme five years ago may already be working with partially outdated knowledge in the most dynamic technology areas. There is no established mechanism in any of the three countries studied for systematic, ongoing technical updating of TVET instructors at the pace that Industry 4.0 change requires.

Most instructor development programmes in Sub-Saharan Africa focus on pedagogy — delivery skills, assessment methods, classroom management — rather than technical content updating (Card etal., 2018). The few technical upgrading programmes that exist are typically one-off workshops funded by development partners, delivered once and not repeated. They leave instructors better informed about

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Industry 4.0 as a concept but rarely better equipped to actually teach the practical skills involved. The structural problem is that TVET instructor salaries are not competitive with industry salaries for people with current Industry 4.0 technical skills, so the TVET system tends to retain instructors with outdated knowledge while those with current knowledge stay in or move to industry.

Infrastructure and Connectivity

Physical infrastructure deficits in Sub-Saharan TVET institutions have been documented extensively in the comparative education literature (Atchoarena & Delluc, 2002; World Bank, 2022). Unreliable power supply, inadequate workshop space, and ageing equipment are longstanding problems that predate Industry 4.0. The specific infrastructure requirements for Industry 4.0 training add a new dimension to this challenge: reliable broadband connectivity at speeds sufficient for cloud-based learning platforms and simulation software, programmable automation equipment, licensed CAD/CAM and data analysis software, and backup power generation sufficient to maintain a computing environment during interruptions. None of these is cheap, and several are logistically difficult to sustain in secondary cities and rural areas (International Energy Agency. 2022).

What makes the infrastructure question particularly frustrating in the African TVET context is that equipment is sometimes present but not functional. Development partner donations and government procurement exercises periodically bring Industry 4.0 relevant equipment into institutions that lack the instructors, software licences, maintenance budgets, or power reliability to use it effectively. The result is a category of asset that features positively in institutional inventories but contributes nothing to actual training — a distinction that aggregate infrastructure statistics consistently fail to capture.

METHOD

Sample Design and Study Sites

The study covered forty-two TVET institutions: fifteen in Kenya, fourteen in Ghana, and thirteen in Nigeria. Within each country, institutions were stratified by location (urban, peri-urban, rural), institutional level (national polytechnic or technical university; regional technical college; community-based TVET centre), and funding source (public, private, public-private). The stratification was designed to ensure that the sample captured the full range of institutional contexts, rather than over-representing the well-resourced flagship institutions that feature disproportionately in the existing TVET case study literature (Creswell & Creswell, 2018).

Site selection within each stratum was purposive, based on programme diversity, TVET authority registration status, and availability of enrolment data. Final selection was validated with each country's national TVET authority to ensure no significant institutional type was absent from the sample. Fieldwork was conducted between March and October 2023 by the lead researcher and two trained research assistants per country.

The Industry 4.0 Readiness Index

The I4RI is a composite index built from indicators across four dimensions: curriculum alignment, instructor competency, infrastructure, and institutional governance and partnerships. Table 1 presents the dimensions, sub-indicators, and weightings. Dimension weights were determined through an expert consultation involving eighteen TVET specialists, industry representatives, and technology policy researchers, using a modified Delphi process to build consensus on relative importance (Patton, 2015).

Table 1. I4RI Dimensions, Sub-indicators and Weightings.

Dimension	Key Sub-indicators	Weight
Curriculum Alignment	I4.0 content coverage in modules; industry validation date; revision frequency; employer-validated outcomes	30%
Instructor Competency	Digital literacy assessment; practical I4.0 skills test; industry experience; professional development recency	28%
Infrastructure	Digital equipment availability; connectivity speed; power reliability; software licences; workshop condition	27%
Governance and Partnerships	Active industry advisory board; instructor secondment programme; graduate tracer system; employer feedback mechanisms	15%
Total	—	**100%**

Data Collection

Four instruments were used. First, a structured institutional survey of eighty-nine items, administered to the principal or academic registrar of each institution, covering curriculum documentation, staff qualifications, equipment inventories, and partnership arrangements. Second, a practical skills assessment administered to a random sample of instructors at each institution, testing competency in four Industry 4.0 domains: basic PLC programming, CAD file creation and modification, interpretation of data from a simulated production monitoring dashboard, and diagnosis of a fault in a networked industrial sensor setup. Third, structured interviews with 186 instructors and 312 graduates who had completed their programmes within the preceding thirty-six months. Fourth, structured classroom and workshop observations at each institution using a standardised observation protocol (Patton, 2015).

Analysis

Quantitative data were analysed using descriptive statistics and mixed linear regression to identify institutional predictors of I4RI scores. Qualitative data from interviews and observations were subjected to thematic analysis using a codebook developed both deductively from the I4RI dimensions and inductively refined during early fieldwork. Inter-rater reliability was checked for qualitative coding across country research teams and achieved an average Cohen's kappa of .79, indicating substantial agreement (Cohen, 1960).

RESULTS

Overall I4RI Scores

The mean I4RI score across all forty-two institutions was 31.4 out of 100. No institution in the sample reached 60, which was defined as our conservative threshold for basic readiness — the level at which an institution can reasonably claim to be giving graduates a foundational capacity to work in Industry 4.0 environments. The highest-scoring institution in the sample, a national polytechnic in Nairobi, reached 58.7. The lowest-scoring, a rural community TVET centre in northern Nigeria, scored 9.1. Table 2 presents the summary results by country and institution type.

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Table 2. I4RI Summary Statistics by Country and Institution Type.

Category	N	Mean	Min	Max
All institutions	42	31.4	9.1	58.7
Kenya	15	36.8	14.2	58.7
Ghana	14	30.1	11.3	52.4
Nigeria	13	26.7	9.1	48.2
National polytechnic / Technical university	9	47.2	38.1	58.7
Regional technical college	20	30.3	17.8	44.1
Community TVET centre	13	19.6	9.1	28.3
Urban location	18	41.3	22.4	58.7
Peri-urban / Rural	24	24.1	9.1	38.6

Several of these figures deserve particular emphasis. The urban-rural gap of 17.2 index points is large enough to represent a structural inequality, not a marginal variation. An institution averaging 24.1 is not offering qualitatively similar training to one averaging 41.3, regardless of whether both issue the same TVET certificate. The community TVET centres, with a mean of 19.6 and a minimum of 9.1, are the institutions that serve predominantly rural and lower-income students. These are the students for whom TVET is the primary — sometimes only — pathway into formal employment, and they are attending the least-equipped institutions in the system (UNESCO-UNEVOC, 2021).

Curriculum Alignment

Curriculum misalignment contributes 38 percent of the total gap between the observed mean I4RI and the maximum possible score, making it the single largest driver of unreadiness. Table 3 presents the detailed sub-indicator results.

Table 3. Curriculum Alignment Sub-indicator Results.

Sub-indicator	Kenya	Ghana	Nigeria	All
Programmes with any I4.0 content	41%	29%	18%	30%
Mean curriculum revision lag (years)	3.8	5.1	6.7	5.2
Programmes with employer-validated outcomes	34%	22%	11%	23%
Graduates rating curriculum as highly relevant	28%	21%	16%	22%
Instructional time allocated to digital skills	8.4%	5.9%	3.8%	6.2%

The average curriculum revision lag of 5.2 years across the sample is a figure that needs to be understood in context. A competency standard validated five years ago describes the technology environment of 2018 or 2019 — before large-scale commercial deployment of collaborative robots in African manufacturing, before cloud-based production management systems became widely accessible to mid-sized firms, and before AI-assisted quality inspection moved from pilot projects to routine deployment. Training to that standard today is, in a meaningful sense, training for a job that no longer exists in its original form (Wesselink et al., 2007).

Only 30 percent of sampled programmes contained any Industry 4.0 content, and in many cases this consisted of a single introductory computing module that predated the Industry 4.0 concept. The Nigerian sample was most concerning: only 18 percent of programmes had any explicit I4.0 content, and the average revision lag of 6.7 years placed most programmes on pre-2017 standards. This is particularly striking given that Nigeria's own national economic policy formally acknowledged Industry 4.0 as a strategic priority in 2017 (Federal Republic of Nigeria., 2017).

Graduate perceptions confirmed what the documentary evidence suggested. Only 22 percent of graduates across the full sample rated their curriculum as highly relevant to the work they were doing or looking for. In interviews, graduates were often candid about specific gaps. One electrical engineering graduate from a technical college in Ghana described the experience this way: "I could read a wiring diagram, but when I arrived at the factory everything was PLC-controlled. They expected me to write ladder logic. I had never heard of it at school." This kind of account was not unusual — it came up in different forms in interviews across all three countries, and it captures the practical consequence of the curriculum lag in a way that aggregate statistics alone do not.

Instructor Competency

The practical skills assessment administered to instructors produced results that were difficult to view as anything other than a crisis. Across the four assessed domains, instructors achieved a mean correct-response or task-completion rate of 34 percent. In PLC programming specifically — arguably the most fundamental Industry 4.0 skill for manufacturing technicians — only 22 percent of instructors could correctly complete even a basic ladder logic task. Table 4 presents the results by domain and country (Moretti, 2012; Fantini et al., 2020).

Table 4. Instructor Competency Assessment — Mean Scores by Domain and Country (% correct or competent).

Assessment Domain	Kenya	Ghana	Nigeria	All
Basic PLC programming	28%	22%	14%	22%
CAD file creation and modification	44%	38%	29%	37%
Production dashboard data interpretation	51%	42%	31%	42%
Networked sensor fault diagnosis	30%	26%	18%	25%
Overall mean	**38%**	**32%**	**23%**	**31%**

National polytechnic instructors achieved an overall mean of 51 percent, reflecting some exposure to industry-updated content and occasional industry secondments. Community centre instructors averaged 18 percent — a result consistent with many having received no substantive technical updating since qualifying as instructors, sometimes two decades or more previously (Hanushek & Woessmann, 2015). In interviews, instructors were frequently honest about their own gaps and expressed genuine frustration about the lack of accessible upskilling opportunities. One mechanical engineering instructor in Kaduna described attending a one-week "Industry 4.0 awareness" workshop three years earlier, funded by a development partner, as his only exposure to the topic in fourteen years of teaching. A donated PLC trainer at his institution had been unused for two years because no one on staff knew how to operate it with enough confidence to teach from it.

This account captures something important: the problem is not usually instructor unwillingness. It is a structural absence of the sustained, practically oriented technical development programmes that would

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allow instructors to genuinely acquire and maintain Industry 4.0 competency. Awareness workshops are not sufficient. Neither is isolated equipment donation without the accompanying instructor capability to use it.

Infrastructure

Infrastructure availability varied enormously across the sample. The most striking finding is that zero percent of community TVET centres possessed any PLC or automation training equipment. This is not surprising to anyone who works in these institutions, but it has a direct and unavoidable implication: if the training environment contains no Industry 4.0 technology, Industry 4.0 skills cannot be meaningfully taught in that environment. Table 5 presents the infrastructure results by institution type (Tilak, 2002).

Table 5. Infrastructure Availability by Institution Type (% of institutions reporting).

Infrastructure Item	Nat. Polytechnic	Regional College	Community Centre
Reliable broadband (>10 Mbps)	78%	31%	8%
Any PLC or automation equipment	89%	25%	0%
Operational 3D printer	56%	10%	0%
Licensed CAD software	67%	18%	5%
Backup power (generator or solar)	100%	45%	15%
Computer-to-student ratio ≥ 1:4	89%	40%	12%
Any operational simulation software	44%	8%	0%

Power supply reliability emerged as an underappreciated constraint even where equipment existed. A principal at a regional college in Ghana's Brong-Ahafo region described a donated CNC machine that had been installed eighteen months prior but had been used for actual instruction fewer than thirty times in that period, primarily because the combination of frequent power interruptions and instructor anxiety about mid-session failures had made regular use impractical (Gratton, 2011).

Across the full sample, seventeen instances were documented of Industry 4.0 relevant equipment — PLCs, CNC machines, 3D printers — that had been donated but was non-functional at the time of the visit. In twelve of those cases, the reason was either expired software licences, absence of spare parts, or no instructor who could confidently operate the equipment. Equipment donated without accompanying instructor training, software maintenance provision, and a spares budget consistently becomes a non-functional cabinet asset rather than a training resource.

Governance and Industry Partnerships

Governance and partnerships, weighted at 15 percent of the I4RI, functioned in qualitative analysis as a strong mediating factor across the other three dimensions. Institutions with active industry advisory boards, functioning instructor secondment arrangements, and operating graduate tracer systems consistently performed better across all dimensions, not just governance (Porter, 1998).

Only eleven of the forty-two institutions had an industry advisory board that met at least twice a year and whose recommendations had produced observable curriculum or equipment changes in the preceding three years. The majority had boards in name only — assembled for accreditation purposes and inactive between visits. This matters because a functioning advisory board is the primary mechanism through which changes in employer skill requirements can reach curriculum developers promptly. Without one, curriculum revision depends on informal signals — individual instructors noticing that graduates are reporting skill gaps, or a principal who happens to maintain personal industry relationships — which is slow and unreliable (Porter, 1998).

DISCUSSION, CONCLUSIONS, and SUGGESTIONS

The findings tell a consistent story across three countries and three institution types, and that consistency is itself significant. A mean I4RI of 31.4, with no institution reaching the basic readiness threshold of 60, is not the result of a few poorly performing outliers dragging down a generally adequate system. It reflects a systemic condition in which the TVET sector as a whole is operating at a significant distance from what Industry 4.0 labour markets require (Allais, 2020).

The results also reveal something about which institutions are pulling the average down most sharply and why that matters distributionally. Community TVET centres, with a mean of 19.6, serve disproportionately rural, lower-income students for whom TVET is often the primary available pathway into formal employment. If the gap between what these institutions provide and what Industry 4.0 employers require continues to widen, the TVET system will increasingly function as a mechanism that reproduces existing inequality rather than reduces it. Students who can access urban polytechnics — generally those from more economically advantaged backgrounds — will receive training that is at least partially aligned with modern employer expectations. Those who cannot will receive training that is substantially further behind (UNESCO-UNEVOC, 2021; Acemoglu & Robinson, 2012).

The finding that active industry partnerships mediate performance across all readiness dimensions offers one source of optimism in otherwise challenging results. Institutions that had maintained functional advisory boards and instructor secondment arrangements performed better on curriculum alignment, instructor competency, and infrastructure utilisation than comparable institutions without those arrangements — even when operating with similar budgets. This suggests that institutional leadership choices and governance quality can partially compensate for resource constraints, and that TVET reform programmes focused exclusively on physical resourcing are missing an important lever (Porter, 1998).

It is also worth noting what the findings do not show. They do not show that Industry 4.0 is uniformly and immediately relevant across all Sub-Saharan TVET contexts. Many graduates from the institutions in this sample will work in environments that are not yet significantly transformed by Industry 4.0 technologies. The concern is not that all TVET graduates immediately need to be able to programme collaborative robots. The concern is that the institutions in this study are not even equipping graduates with the foundational digital literacy and systems orientation that will allow them to adapt as the technology environment changes — and that gap will compound over the working lives of the students currently passing through these institutions (Banga, 2019).

Policy Implications

The findings of this study carry specific implications for each of the major actors in the Sub-Saharan African TVET ecosystem. What follows is not a general call for more investment in TVET — a call that has been made many times before without sufficient effect. It is an attempt to identify the specific structural changes that the evidence supports.

For National TVET Authorities: Reform the Curriculum Revision Architecture

The single most important policy change that national TVET authorities could make is to separate fast-moving technology-specific content from stable foundational content within programme qualifications, and to subject them to different revision cycles. Foundational modules in mathematics, technical drawing, materials science, and basic electrical principles change slowly and do not need annual review. Technology-specific modules — covering, for example, PLC programming for a particular family of controllers, or data interpretation from a specific class of industrial monitoring system — need to be updateable on an annual or biennial basis without triggering a full programme re-accreditation process (Wesselink et al., 2007; OECD, 2019).

Australia and Singapore have introduced short-form credential mechanisms — skill sets and micro-credentials — that allow rapid updating of occupational currency without disrupting whole-qualification architecture. There is no structural barrier to adopting a similar approach in African TVET systems. The barriers are political and bureaucratic: certification agencies and qualification authorities have incentives to maintain full programme review processes because that is where their institutional role and revenue are concentrated. Overcoming those incentives requires deliberate ministerial direction rather than technical consensus.

Industry involvement in curriculum development also needs to become substantive rather than ceremonial. The current model, in which industry is consulted during curriculum review and then has no ongoing role, is insufficient for the pace of technological change. Employer co-investment in curriculum development — where companies contribute both funding and technical expertise to the development of modules covering their technology ecosystem — would create market incentives for timely updating and give employers a stake in the quality of what is produced. Several employer associations in Kenya and Ghana already have the institutional capacity to play this role if TVET authorities create the mechanisms that would make it worthwhile (Mumo & Mwangi, 2021).

For Ministries of Education: Address the Instructor Competency Deficit Structurally

The instructor competency data in this study describe a problem that cannot be solved through occasional professional development workshops. Organising periodic one-week industry awareness events and treating that as instructor upskilling is a well-documented failure mode across the region, and the assessment results confirm it (Card et al., 2018). Three structural interventions are warranted.

First, mandatory industry secondment should become a condition of TVET instructor employment rather than a voluntary enrichment activity. A minimum of four to six weeks per year working in a relevant Industry 4.0 environment would provide instructors with the experiential exposure that no classroom-based training can replicate. Germany and Switzerland have maintained versions of this model for decades, and the evidence from those systems is that instructor industry currency directly and measurably improves training quality. Making secondment a formal employment requirement, with agreed placement arrangements with employer partners, would require regulatory change but is achievable within existing TVET governance frameworks in all three countries studied (Akyeampong, 2010; Kluve, 2010).

Second, national TVET instructor registration should incorporate demonstrated competency in current technology domains as a re-registration condition. Currently, none of the three countries studied has any such requirement. An instructor who qualified in electrical installation twenty years ago retains full teaching registration in that field regardless of how much the underlying technology has changed. Creating a re-registration cycle with a practical competency component aligned to current industry standards would create a systematic, institution-independent mechanism for identifying and addressing obsolescence — and would make the true scale of the upskilling need visible in national workforce data for the first time (Allais, 2014).

Third, regionally distributed Industry 4.0 instructor development centres, co-funded by TVET authorities and industry, would provide accessible, sustained, practically oriented technical development for instructors who cannot access it through their own institutions. The capital cost of equipping such centres is substantial, but substantially lower than equipping every TVET institution individually, and the specialist expertise needed to deliver quality Industry 4.0 instructor training is more effectively concentrated in a small number of well-resourced centres than diluted across hundreds of institutions with inadequate resources and equipment (ILO, 2020).

For Development Partners: Rethink Equipment Donation Models

The seventeen instances of donated but non-functional Industry 4.0 equipment documented in this study represent a familiar and avoidable failure mode. Equipment donations to TVET institutions are frequently made on a project-cycle timeline that prioritises visible capital disbursement over sustainable operational impact. A CNC machine delivered and photographed for a project report counts as a delivered output whether or not it is ever used for instruction. This creates systematic incentives for the wrong kind of investment (Tilak, 2002).

Development partners should require that any Industry 4.0 equipment donation is accompanied by a minimum three-year commitment to instructor training, software licence maintenance, and technical support provision. They should also prioritise institutional capacity — governance quality, industry partnership depth, power reliability — over equipment quantity when selecting institutions for support. Concentrating resources on institutions with the governance and human capacity to use them effectively will produce more learning outcomes per dollar invested than spreading the same resources thinly across all institutions as a gesture of equity (Dougherty, 2016).

Longer-term, development partners have an important role to play in supporting the regional hub model proposed above — particularly in identifying and co-financing institutions in secondary cities that can serve as accessible Industry 4.0 training centres for a wider catchment of students and instructors than their immediate host communities.

For TVET Institutions: Prioritise Governance Before Equipment

The finding that active industry partnerships mediate performance across all readiness dimensions has a direct implication for institutional leadership: investing time and effort in building and maintaining genuine industry relationships is at least as important as lobbying for additional equipment. The better-performing regional colleges in this sample had not received dramatically more resources than lower-performing comparable institutions. What distinguished them was sustained effort by leadership to make industry advisory boards functional, to negotiate instructor secondment agreements, and to use graduate tracer data as evidence to drive curriculum discussions (Porter, 1998).

Principals and academic registrars who do not currently have functional industry advisory mechanisms should treat establishing them as the first institutional priority — before curriculum reform, before equipment procurement requests. The data from this study suggest that functional governance and industry relationships are what make curriculum revision and equipment use effective. Without them, both curriculum reform and equipment investment tend to produce less impact than they should.

Addressing the Two-Tier Risk

The 27.6-point I4RI gap between national polytechnics and community TVET centres should be treated as a warning signal that current patterns of TVET development are creating a structurally unequal system, with consequences that will compound over time. If left unaddressed, this gap will translate into diverging employment outcomes, earnings, and economic mobility for the students from different institution types — with the rural, lower-income students who disproportionately attend community centres receiving systematically worse preparation for the labour market that is emerging around them (UNESCO-UNEVOC, 2021; Acemoglu & Robinson, 2012).

Addressing this requires a combination of redistribution and access measures. Scholarships or transport subsidies enabling rural students to access better-equipped regional training hubs, online and blended learning components that reduce the daily travel burden, and mobile intensive training units that bring Industry 4.0 equipment to community centres for block release periods are all measures that merit serious policy consideration. They will not eliminate the structural gap — that requires sustained investment in the institutions themselves — but they can reduce its effect on individual students while longer-term institution-building takes place (Hanson, 2012).

Conclusion

This study asked a direct question: are TVET institutions in Sub-Saharan Africa ready to train workers for an Industry 4.0 economy? Based on a systematic comparative assessment of forty-two institutions in Kenya, Ghana, and Nigeria, the answer is no — and the scale of the gap is larger and more structurally entrenched than existing policy documents or institutional self-assessments acknowledge.

A mean I4RI score of 31.4 out of 100, with no institution reaching the basic readiness threshold and the worst-performing quarter of the sample scoring below 20, is not a picture of a system that is close to where it needs to be. The dimensions of the failure are interrelated and mutually reinforcing: curricula that were last revised before much of the relevant technology was in wide industrial use, instructors who have received no meaningful technical updating in Industry 4.0 domains, infrastructure that is either absent or non-functional in the majority of institutions, and governance structures that have not successfully integrated industry as a genuine partner in training system development.

None of this is inevitable. The higher-performing institutions in the sample demonstrate that meaningful progress is possible within current resource constraints, given the right governance priorities and industry relationships. The policy interventions described in Section 6 are specific, actionable, and proportionate to the scale of the problem. Rapid-cycle curriculum updating, mandatory instructor secondment, competency-linked re-registration, regional hub infrastructure, and equity-oriented access measures are all achievable within the existing legislative and institutional frameworks of the countries studied.

The cost of inaction is not abstract. Industry 4.0 is already operating in the workplaces where TVET graduates seek jobs. Every cohort that passes through a training system that is not teaching them what those workplaces require is a cohort entering the labour market with a deficit that will follow them throughout their working lives. Closing the Industry 4.0 readiness gap in Sub-Saharan Africa's TVET systems is, ultimately, an investment in the economic futures of the millions of young people who depend on those systems as their principal pathway to productive employment.

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Ethics and Conflict of Interest

Ethical approval was obtained from the University of Eldoret Research Ethics Committee prior to data collection. Informed written consent was obtained from all individual participants. All institutional data are reported in aggregate form to preserve confidentiality. The author confirms that artificial intelligence tools were used solely for the purposes of language editing, grammar checking, and formatting during the preparation of this manuscript. All research design, conceptualisation, data collection, analysis, interpretation of findings, and the intellectual content of the article are the original work of the author. No AI tool was used to generate or fabricate research data, statistical results, or substantive arguments.

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Data Availability

The institutional survey instrument, observation protocol, and aggregated anonymised datasets supporting this study are available from the corresponding author upon reasonable request.

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