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RENEWABLE ENERGY EDUCATION FOR SUSTAINABLE ENERGY TRANSITION

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Summary

The shift to sustainable and solar energy depends on people who can plan, finance, build, manage, maintain, and govern energy systems. Renewable energy education is therefore essential, yet gaps remain in curriculum integration, training infrastructure, access, and alignment with evolving industry demands, particularly in developing countries. This study employs a qualitative analytical approach and an integrative review of peer-reviewed and selected institutional literature to examine how education can strengthen capacity building, skills development, and knowledge dissemination. The evidence is organised into six themes: curriculum relevance, applied learning, educator and infrastructure capability, industry and institutional collaboration, inclusion and access, and lifelong learning. The synthesis shows that effective provision must integrate energy literacy, technical proficiency, systems thinking, safety, digital capabilities, project and business expertise, and policy awareness. A structured framework linking labour-market signals with practice-based delivery, curriculum renewal, inclusion, quality assurance, and continuous feedback is proposed, with particular relevance to solar-growth contexts such as Botswana.

Renewable energy education, energy transition, capacity building, skills development, solar energy

Field of application for the findings: Renewable energy education and training, capacity development, solar energy systems

Addressed audience: Researchers, educators, policymakers, training providers and renewable energy practitioners

1. Introduction

Climate change mitigation, energy security, affordability, and sustainable development have made the shift to sustainable energy systems a global priority. The focus has changed from whether clean energy systems are theoretically feasible to whether institutions and labour markets can provide them at the necessary pace and quality due to the rapid cost reductions and deployment of solar photovoltaic (PV), wind, and other renewable technologies. In 2024, there were 16.6 million jobs worldwide in renewable energy, with solar PV continuing to be the leading sector (IRENA and ILO, 2026). Growth in employment, however, does not always result in decent or locally accessible work. The availability, location, and calibre of talents, as well as the ability of educational systems to foresee technological change rather than just respond to it, will determine this (Hanna et al., 2024; Weishaupt and Quiceno-Soto, 2026).

Renewable energy education (REE) encompasses formal programmes, technical and vocational education and training (TVET), university courses, professional development, apprenticeships, community learning, and public awareness. It does more than just produce installers. Technicians, engineers, planners, educators, regulators, financiers, procurement officials, entrepreneurs, project managers, and knowledgeable users are all necessary for energy transformations. Various levels and combinations of technical, managerial, digital, environmental, and social competence are required for these actors. Thus, education links the use of technology with institutional capacity and public involvement.

The fact that labour demand and energy technologies advance more quickly than curricula and training capacity is a recurring worry. Kandpal and Broman (2014) reported low laboratory resources, a lack of qualified educators, and unequal global provision. Similar findings from recent workforce evaluations include poor demand forecasting, fragmented skills governance, and inadequate coordination between public policy, business, and education (Hanna et al., 2024; Weishaupt and Quiceno-Soto, 2026). These shortcomings interact with inadequate institutional resources, unequal access, and slow local value-chain growth in Africa. Inadequate technical, policy, financial, and governance expertise might directly limit the adoption of renewable energy, according to data from South African municipalities (Oladejo, 2025).

Botswana provides an instructive developing-context lens. A tiered national training architecture including solar-water-heating and PV maintenance, artisan training, supervisory education, and decision-maker development is required, according to Jain et al. (2002). The diagnosis acknowledged that improved facilities and training at various occupational levels were necessary for successful adoption. Over twenty years later, the relationship between education and implementation is even more important due to Botswana's expansion of grid-connected solar power and its broader aspirations for energy access. For utility-scale PV, digital monitoring, storage integration, quality assurance, procurement, environmental and social governance, and inclusive workforce involvement, historical advice should be reinterpreted rather than merely rehashed.

This paper examines REE as a key component of the sustainable and solar energy transition, with particular emphasis on capacity building, workforce development, and knowledge dissemination. It answers three questions: (i) what constraints most frequently prevent effective REE; (ii) what elements of educational design address those constraints; and (iii) how these elements can be put together into an organised, inclusive, and industry-aligned framework. Without presenting the research as an empirical assessment of a single program, the contribution is an integrated framework that links education inputs, learning processes, enabling contexts, and transition outcomes.

2. Conceptual background

2.1. Education as transition infrastructure

Rather than seeing skills as an external labour-market afterthought, energy-transition study increasingly views skills as a component of the socio-technical system. Only individuals and organisations with the necessary skills to design, approve, build, run, and maintain infrastructure can install it. Reliability, safety, local acceptability, policy implementation, and the preservation of economic value are all impacted by human capabilities. Education is consequently a form of transition infrastructure: it creates absorptive capacity for technology and equips institutions to learn as technologies, markets and regulations evolve.

This knowledge avoids a limited comparison of skills to temporary job matching. Entry-level training, occupational specialisation, retraining current employees, ongoing professional development, and public energy literacy must all be included in a sustainable transition. It must also consider inclusion, regional distribution, and employment quality. According to Hanna et al. (2024), the employment literature focuses more on job numbers than on job quality, occupational profiles, and mismatches in regional skills. Therefore, an education strategy should include not only the number of trained individuals but also who may enrol in training, what they can demonstrate, where their expertise is required, and whether learning promotes long-term career prospects.

2.2. Competence for renewable-energy practice

Competence is the combined capacity to use professional behaviour, judgement, practical skill, and knowledge in a given situation. Renewable-energy practice requires disciplinary foundations, but it also involves systems with environmental, economic, regulatory, and social consequences. According to research on sustainability education, interpersonal competence, normative reasoning, systems thinking, anticipatory thinking, and strategic action are all mutually reinforcing skills (Wiek et al., 2011; Brundiers et al., 2021). In engineering and technical programmes, these capabilities should supplement, rather than replace, technology-specific expertise, safety, and diagnostic skills. Table 1 summarises the principal competence domains required in renewable-energy education, together with their representative learning outcomes and relevance to the energy transition.

Tab. 1: Competence domains for renewable-energy education

Domain	Representative learning outcomes	Transition relevance
Technical and safety	Size components; read diagrams; install, commission, test, troubleshoot and maintain systems; apply electrical and occupational safety.	Supports quality, reliability, safe work, and asset performance.
Digital and data	Use simulation, monitoring and data-acquisition tools; interpret performance data; recognise cybersecurity and data-quality issues.	Enables modern design, remote operation, and evidence-based maintenance.
Systems and sustainability	Relate resources, technologies, grids, storage, demand, life cycles, and environmental effects.	Avoids technology-only decisions and supports whole-system optimisation.

Project and commercial	Estimate costs; evaluate risk; understand procurement, contracts, bankability, and quality assurance.	Connects technical decisions to viable implementation.
Policy, social and ethical	Interpret standards and regulation; engage stakeholders; address equity, gender, and community impacts.	Strengthens legitimacy, compliance, and a just transition.
Adaptive and interpersonal	Communicate, collaborate, solve unfamiliar problems, and pursue continuous learning.	Sustains competence amid rapid technological change.

Table 1 translates broad sustainability competencies into observable renewable-energy outcomes. The domains are related on purpose. For instance, electrical expertise, monitoring data, safety judgement, and client communication may be necessary for a PV professional to make a diagnostic choice. Technical specifications, stakeholder accountability, lifecycle costing, and standards may all be necessary for a project manager's procurement decision. Graduates from fragmented curricula that separate these dimensions may be conceptually literate but find it difficult to conduct integrated work.

3. Methodology

3.1. Research design

The study adopted a qualitative and analytical design using an integrative narrative review. This design was selected because the research purpose was to interpret relationships among education, skills, institutional capacity, and energy-transition implementation, rather than estimate a pooled intervention effect. The method follows the approach stated in the accepted abstract: analysis of relevant literature, educational frameworks, and documented training practices, with attention to curriculum design, accessibility, industry alignment, institutional collaboration, and stakeholder engagement.

3.2. Search and selection approach

Searches combined the abstract keywords—renewable energy education, energy transition, capacity building, skills development, and solar energy with terms for curriculum, TVET, higher education, workforce, green skills, project-based learning, laboratories, industry collaboration, inclusion, Africa, and Botswana. Journal articles that underwent peer review were given priority. Current workforce and educational concerns were established through recent reviews and empirical investigations; seminal competency literature and the Botswana-specific study by Jain et al. (2002) were retained due to their conceptual or contextual significance. Only where authoritative labour-market, policy, or national background was needed were certain reports from IRENA, ILO, UNESCO, and the Government of Botswana used.

Sources that addressed at least one of the following four analytical relationships were included: (i) transition-driven demand for capabilities; (ii) design or delivery of education related to renewable energy and sustainability; (iii) barriers affecting access, relevance, or training capacity; or (iv) mechanisms linking public institutions and industry with education providers. Sources that solely addressed technology performance without taking manpower or education into account were disregarded. There is no claim of comprehensive database coverage or meta-analysis; the method is an analytical review rather than a systematic study.

Tab. 2: Analytical review framework

Stage	Guiding question	Output
Problem framing	Why does the transition create an education and capacity-development requirement?	Definition of education as transition infrastructure.
Evidence identification	Which peer-reviewed and authoritative sources address education, skills, and implementation?	Contextual and thematic evidence base.
Thematic coding	Which barriers, delivery mechanisms and enabling conditions recur across sources?	Six synthesis themes.
Cross-context interpretation	Which findings are broadly transferable, and which require developing-context adaptation?	Context-sensitive implications.
Framework construction	How can the themes form a coherent education system rather than isolated interventions?	Structured REE framework and action priorities.

3.3. Analysis and trustworthiness

Curriculum, infrastructure, accessibility, industry alignment, cooperation, and stakeholder involvement were the deductive categories employed in the analysis, which also allowed for the emergence of other patterns including lifelong learning, digital competency, and quality assurance. Results from international, African, and Botswana-focused sources were compared. Claims were adjusted in accordance with the supporting data: where studies were context-specific, educational interventions were deemed promising; however, recurrent findings from reviews and empirical research were seen as stronger patterns. Each theme was connected to its problem signal, instructional response, and anticipated transition contribution through an audit table. The restrictions of a narrative synthesis are not eliminated, but transparency is increased.

4. Results

4.1. Theme 1: curriculum relevance and integration

The literature frequently notes curriculum fragmentation and lag. Content on renewable energy is frequently provided as a stand-alone option, incorporated sparingly into traditional engineering courses, or kept apart from social, regulatory, and economic aspects. This arrangement can increase awareness without fostering professional competence. While Wang et al. (2021) demonstrate the importance of student-oriented curriculum design that encourages creative application of renewable-energy knowledge, Kandpal and Broman (2014) advocate for provision that is flexible to learner level and societal need. According to da Costa et al. (2025), recent studies on green skills also reveal ongoing discrepancies between school results and employer demands.

A pertinent curriculum ought to be integrated both horizontally and vertically. From fundamental energy literacy to sophisticated design, operation, and leadership, vertical integration fosters advancement. Technical content, digital tools, safety, project economics, legislation, environmental evaluation, and stakeholder issues are all connected through horizontal integration. Each role has a different blend that is suitable. Managers and public officials need procurement, finance, risk, and governance; engineers need design and systems integration; and maintenance staff need extensive diagnostic and safety practice. By suggesting programs at various skill and decision levels, Jain et al. (2002) foresaw this diversified architecture for Botswana. Additionally, cross-regional research demonstrates that provision varies significantly and needs to be adjusted to institutional and labour market situations (Alemam et al., 2025; Okoye et al., 2025).

Renewal mechanisms also affect the relevancy of the curriculum. Storage, smart inverters, remote monitoring, green hydrogen, changing grid codes, and circularity standards are all too much for fixed curricula to manage. Changing practice can be translated into learning outcomes through advisory systems comprising public agencies, professional associations, and employers. Renewal should continue to be controlled by education; industry participation is important, but curriculum should not lose the scientific underpinnings that enable graduates to adapt or turn into vendor-specific training.

4.2. Theme 2: applied, problem- and project-based learning

The necessity of tying theory to real-world application is a second theme. Learners must analyse site and load data, make design decisions, operate equipment properly, identify problems, and explain trade-offs as part of their performance-based renewable energy competency. These abilities cannot be established by passive education alone. While project- and problem-based approaches foster interdisciplinary reasoning, teamwork, and iterative design, DeWaters and Powers (2021) highlight the importance of socio-technical energy courses (Lozano et al., 2017; Zacchia et al., 2022). Research autonomy and engineering thinking have improved, according to evidence from solar-energy STEM project-based learning; nonetheless, the transferability of impact sizes across contexts should be managed carefully (Ramankulov et al., 2026).

Expensive utility-scale technology is not necessary for authentic learning. Calculations, simulations, bench-scale experiments, monitored campus systems, case studies, fault scenarios, and industrial placements can all be included in a layered model. Every layer has a distinct function. Live systems reveal variability and operational limitations; laboratories establish measurement and safety procedures; work-based learning introduces organisational practice; and simulation enables recurrent design exploration. Design files, commissioning documents, risk assessments, troubleshooting logs, performance analysis, and reflective explanations are examples of demonstrable outputs that should be required for assessment rather than just recollection.

4.3. Theme 3: educators and training infrastructure

Without educators, facilities, and operational resources, curriculum reform has insignificant impact. Beyond initial funding, renewable energy labs need equipment that is safe, calibrated, maintained, updated, and readily available. Recurring expenses include software licenses, consumables, sensors, spare parts, internet connection, and technical assistance. Personnel and facilities are identified as key restraints by Jain et al. (2002) and Kandpal and Broman (2014). Donated equipment may become unusable in institutions with limited resources if there is no documentation, training, compatibility, or maintenance assistance.

Educator capacity is equally crucial. To direct research, practical work, and safety, educators and laboratory staff must possess both subject-matter expertise and instructional skills. Although they can increase reach, train-the-trainer approaches necessitate follow-up, communities of practice, and recurring evaluation. Access can be expanded through shared regional facilities, mobile training units, open educational resources, distant laboratories, and thoughtfully created virtual simulations. In situations where occupational competency necessitates physical labour, digital solutions should supplement hands-on experience; replacing installation, wiring, testing, and fault-finding with virtual exposure would create a practical gap.

4.4. Theme 4: industry alignment and institutional collaboration

No single organization has all the data and materials needed for successful REE. Employers see how occupational activities change; educators comprehend how learning progresses; professional associations and regulators set standards; the government determines the priorities for transitions; and communities witness project results. Curriculum co-design, guest teaching, equipment access, placements, applied projects, educator attachments, and graduate evaluations can all benefit from collaboration. Research on university-industry involvement demonstrates that, when roles and learning objectives are explicit, real-world interaction can enhance relevance and learning (Khan et al., 2025).

Instead of being ceremonial, collaboration must be structured. Placements, supervision, or curricular feedback are not guaranteed by memoranda of understanding alone. Responsibilities, safety and insurance, intellectual property, evaluation, equipment use, data access, and review cycles are all specified in effective arrangements. Because they frequently offer installation, maintenance, and entrepreneurial opportunities, small and medium-sized businesses should be included alongside large developers. Because inadequate specifications, oversight, or community involvement might jeopardise otherwise solid projects, public procurers and local government employees also need capacity (Oladejo, 2025).

4.5. Theme 5: inclusive access and participation

If educational approaches perpetuate marginalisation, an energy shift cannot be deemed sustainable. Cost, location, admission restrictions, insufficient prior STEM training, a lack of professional information, rigid schedules, inaccessible facilities, and gendered expectations are some of the obstacles. Research on climate and sustainability education in Africa highlights the significance of inclusive, locally relevant learning and youth involvement (Tshabalala et al., 2025). Recruitment is not the only way to accomplish inclusion; other factors that are important include retention, practical engagement, assessment, mentoring, workplace culture, and advancement.

Bridging modules, scholarships, modular scheduling, accessible facilities, blended access, mentorship, visible role models, and secure learning settings are some ways that program design might adapt. Outreach should start before career decisions are made and should highlight the variety of opportunities in renewable energy, including technical, management, and entrepreneurial positions. Data on participation and completion broken down by gender can show if access results in outcomes. Although inclusive design enhances the transition's talent pool and social legitimacy, it should refrain from portraying under-represented groups as a homogenous category.

4.6. Theme 6: lifelong learning, micro-credentials, and adaptability

Both new entrants and current employees have different tasks as a result of the shift. Thus, initial credentials must be related to lifetime learning. Targeted demands like PV commissioning, energy auditing, digital monitoring, or battery safety can be promptly addressed by short courses and micro-credentials. De Rosa et al. (2024) suggests micro-credentials as a framework for specialised training and retraining in the field of renewable energy. Transparent learning outcomes, reliable evaluation, recognition, and stackability are what determine their worth; an abundance of unverified certifications may be confusing to both companies and students.

Recognition of prior learning can help experienced electricians, artisans, and technicians transition into renewable-energy roles without repeating mastered content. Engineers, educators, regulators, and managers can all benefit from ongoing professional development. Permeability is the main idea: students should be able to enter at the right levels, gain acknowledged competence, switch between higher education and vocational courses, and return for updates throughout their careers.

Tab. 3: Synthesis of barriers, educational responses, and expected outcomes

Barrier	Educational response	Expected contribution
Fragmented or outdated curricula	Role-based competency maps; interdisciplinary modules; scheduled curriculum review.	Relevant and adaptable graduate capability.
Weak theory-practice connection	Laboratories, simulation, field data, projects, placements, and performance assessment.	Work readiness, judgement, and safer practice.
Limited educators and facilities	Trainer development; shared facilities; maintenance plans; blended resources.	Greater delivery capacity and consistent quality.
Poor labour-market feedback	Advisory boards, tracer studies, employer feedback, and educator attachments.	Earlier detection of emerging skills demand.
Unequal access and participation	Bridging routes, modular provision, financial support, mentoring, and inclusive environments.	Broader and fairer participation.
Rapid technology change	Stackable micro-credentials, CPD and recognition of prior learning.	Continuous reskilling and workforce adaptability.

Weak quality assurance	Outcome standards, practical assessment, provider review, and credential transparency.	Trusted competence and reduced installation risk.

5. Discussion

5.1. From isolated training to an education system

The themes suggest that rather than being a collection of separate courses, REE should be built as a system. Policy direction, labour market intelligence, learner needs, educators, facilities, and funding are examples of inputs. Knowledge, practice, projects, and work-based experience are all incorporated into the learning process. Collaboration, inclusiveness, quality control, and feedback are enabling conditions that determine whether a provision is still relevant and available. Occupational competency, increased engagement, institutional capability, and adaptability are among the outcomes. Figure 1 illustrates this relationship.

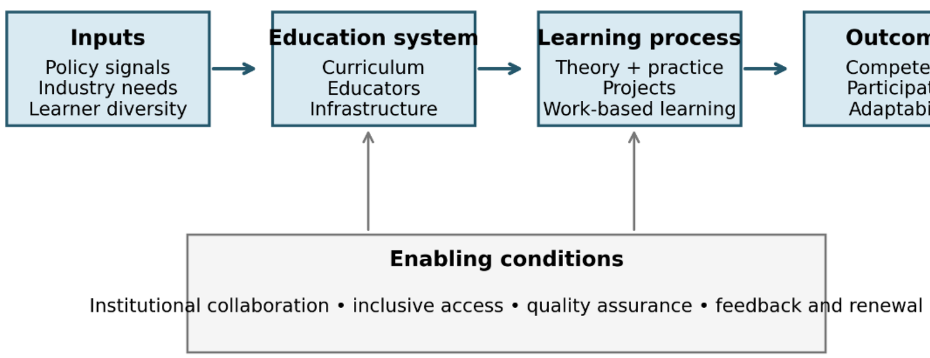

Fig. 1: Structured framework for renewable-energy education as transition infrastructure

It is a cyclical framework. Curriculum renewal and labour market signals are influenced by outcomes and operational experience. This is important because installed systems create learning opportunities and the need for skills is dynamic. Case studies and program updates can be informed by procurement issues, maintenance data, and performance failures. On the other hand, through testing, applied research, and ongoing development, educational institutions can assist business. When information and duties are purposefully exchanged, the connection becomes mutually reinforcing.

5.2. Implications for solar-energy education

Solar energy illustrates the need for differentiated yet connected competence. Applications, safety, and resource potential may all be included in entry-level awareness. Installation, testing, commissioning, maintenance, and fault diagnosis are all necessary for artisan and technician pathways. Engineering pathways include modelling, optimisation, grid integration, and detailed design. Finance, procurement, contracts, risk, environmental and social management, and quality assurance are all necessary for project and leadership pathways. It is ineffective to teach all students the same material at the same depth, and it is equally problematic to divide roles so drastically that they are unable to communicate.

Tab. 4: Illustrative role-based learning architecture for solar energy

Learner/role	Core emphasis	Suitable learning evidence
School/community learner	Energy literacy, applications, responsible use, and career awareness.	Simple energy audit, solar experiment, or community communication product.
Installer/artisan	Site safety, mounting, wiring, protection, testing and installation quality.	Observed practical test and compliant installation record.
Technician	Commissioning, monitoring, preventive maintenance, diagnostics, and documentation.	Fault-finding exercise, performance log, and maintenance plan.
Engineer/designer	Resource assessment, sizing, simulation, grid/storage integration, and standards.	Defensible system design using real or realistic constraints.
Project/finance professional	Feasibility, lifecycle cost, procurement, risk, contracts, and bankability.	Investment case, procurement specification, or risk register.
Public decision-maker	Policy, regulation, planning, procurement oversight, and stakeholder engagement.	Policy or procurement appraisal based on a contextual case.

Educator/trainer	Technical updating, pedagogy, assessment, safety, and inclusive facilitation.	Validated learning design and observed teaching/practical supervision.

Shared foundations and later specialisation are supported by this architecture. It also explains why a degree by itself might not demonstrate practical ability and why brief awareness seminars cannot replace vocational qualification. Credentials ought to convey the skills that an individual has been evaluated for. Curricula and assessments should clearly align with any regulations that call for certification or licensure.

5.3. Implications for Botswana and comparable developing contexts

Botswana's robust solar resources and growing project pipeline present a chance to link local capacity with national deployment. Because it suggested tiered provision and facility upgrades instead of a single university course, the 2002 Botswana study is still noteworthy (Jain et al., 2002). These days, the criterion is more expansive. Grid studies, data analytics, asset management, environmental and social compliance, procurement, and contract management are all necessary for utility-scale projects, and dispersed systems still need qualified installers and maintenance staff. The project lifetime should be covered by education planning, which should differentiate between short-term construction peaks and long-term operation and maintenance capacity.

A national labour-market function or renewable-energy skills observatory would be a useful place to start. Occupations, projected project phases, current programs, enrolment and completion, educator capacity, facilities, certification requirements, and employer-reported gaps might all be mapped. Such a system does not have to be a brand-new organization; it may be a joint effort by pertinent ministries, educational institutions, utilities, industry, professional associations, and the energy regulator. Its usefulness is in transforming disjointed signals into planned training and curriculum choices.

Collaboration on a regional level is also important. It could be costly for each institution to replicate specialised equipment and knowledge. Efficiency can be increased by open learning resources, regional certification recognition, shared short courses, and trainer exchanges. Local adaptability is still crucial, though. The laws, climate, system setups, occupational practices, and learner demands of Botswana should all be reflected in imported content. Successful and unsuccessful local case studies can increase the legitimacy and use of learning.

5.4. Inclusion as a quality dimension

Inclusion is sometimes positioned as a separate social objective after technical quality has been addressed. The synthesis suggests it is the component of the educational system's overall quality. Programs cannot provide the necessary personnel if they are not financially or geographically accessible. Completion may mask unequal competence if practical activities are assigned unevenly. Recruitment initiatives will be ineffective if learners receive career information too late. Therefore, program design and review should incorporate inclusive pedagogy, accessible scheduling and facilities, transparent selection, mentoring, and disaggregated result monitoring.

5.5. Quality assurance and evaluation

Activity, learning, transfer, and transition outcomes should all be distinguished in program evaluation. Activity measurements include participant and workshop counts. Certification and proven proficiency are learning metrics. Transfer is shown by workplace application, employer evaluation, and decreased performance issues. Transition outcomes are related to increased involvement, local employment, safer systems, and dependable operation. Each step makes attribution more challenging, but a balanced monitoring system can prevent attribution from being equated with impact.

Tab. 5: Suggested indicators for monitoring renewable-energy education

Level	Illustrative indicators	Interpretive caution
Access	Applications, enrolment, geographic reach, affordability, participation by gender and underrepresented group.	Enrolment alone does not show equitable experience or completion.
Delivery capacity	Qualified educators, functional training stations, learner-to-equipment ratio, placement availability.	Assets should be measured by usability, not ownership.
Learning	Practical-assessment pass rate, competence by domain, portfolio quality, credential completion.	Assessment validity and consistency must be established.
Transfer	Employment/role transition, supervisor feedback, task performance, CPD application.	Labour-market conditions also affect employment.
System outcome	Installation quality, safety incidents, local workforce share, asset availability, curriculum-response time.	Education is one contributor among policy, finance, and market factors.

Program approval, trainer competency, laboratory safety, practical assessment moderation, industry evaluation, and graduate feedback are all important components of quality assurance. Because their brief duration can give the impression of agility without enough depth, micro-credentials need special consideration. Their legitimacy can be safeguarded by explicit prerequisites, hypothetical learning time, assessment data, and advancement paths.

5.6. Proposed implementation sequence

A staged sequence can be used to operationalise the framework. The sequence is a useful method of coordinating diagnosis, design, delivery, and renewal rather than a strict national blueprint.

- Create a demand and supply map by identifying key technologies, project stages, jobs, ongoing initiatives, facilities, and gaps in access.
- Establish competency profiles by outlining role-based learning objectives in the technical, digital, commercial, social, and adaptive domains.
- Co-design routes that link workplace learning, TVET, colleges, schools, micro-credentials, and ongoing professional development
- Boost delivery capacity by training instructors and technical personnel, as well as by providing, maintaining, and securely running labs and digital platforms.
- Integrate inclusion and support: from recruiting to advancement, address financial, regional, cultural, disability-related, and prior-learning barriers.
- Evaluate performance using transparent credentials, moderated practical evaluation, and real tasks.
- Close the feedback loop by scheduling curriculum renewals using employer, graduate, project-performance, and learner data.

5.7. Curriculum design principles in greater detail

Seven curriculum design principles are supported by the synthesis. First, rather than relying solely on technology labels, learning objectives should be generated from actual responsibilities and duties. The ability of students to examine a site, model a system, understand protection requirements, or assess a project is not fully revealed by the "solar energy" module. Task-based outcomes enhance the alignment of instruction, practical work, and evaluation while making the necessary depth clear. Additionally, they help providers avoid needless duplication by identifying common underpinnings across professions.

Second, before implementing tool-specific methods, programs should lay conceptual underpinnings. To identify when a software output or installation rule is unsuitable, learners must possess sufficient knowledge of mathematics, electrical or thermal science, measurement, and systems. Vendor platforms can make learning relevant and employable, but transfer is limited by an excessive reliance on a sole product. A well-rounded curriculum imparts fundamental concepts, exposes students to representative tools, and evaluates their capacity for decision justification.

Third, there should be a purposeful order for theory and practice. A concept and worked example, simulation, a controlled laboratory task, and an open-ended field or project problem could be the first steps in a successful sequence. After acting, reflection is crucial. Students should describe variations, measurement uncertainty, safety choices, and the effects of different options. Teachers can see implicit judgement in this sequence, which transforms activity into learning.

Fourth, assessment should sample the full competence profile. Although a written exam can effectively assess concepts and computations, it cannot ensure safe tool use, commissioning, or communication on its own. Complementary evidence comes from team projects, design reports, portfolios, oral defences, and practical observation. Individual evidence should still be included in team assessments to prevent uneven competence from being hidden by teamwork. Comparability between instructors and cohorts is enhanced via moderation and shared rubrics.

Fifth, learners' perspectives should be expanded while incorporating local context. Resource conditions, regulations, grid characteristics, procurement practice, and maintenance realities make local cases essential International standards, transferable design principles, and comparative scenarios can help students get ready for future technological advancements and regional mobility. Because it reveals climate, dust, shade, load, and maintenance factors that typical textbook instances may understate, locally gathered operational data can be particularly informative.

Sixth, curriculum renewal must be planned and grounded in research. A broader multi-year review might reevaluate program structure and growth, while an annual minor review can address software, standards, examples, and employer feedback. After significant regulatory changes, persistent field failures, or the introduction of innovative technology, triggered review may be required. Since continuous accumulation results in overburdened programs and shallow coverage, every proposed addition should consider what can be eliminated or merged.

Seventh, inclusion ought to be evaluated at the learning design level. Participation can be influenced by a variety of factors, including group roles, schedules, physical access, protective gear, language, and evaluation circumstances. Teachers should keep an eye on who completes technical tasks in groups, who gets feedback, and who is presumed to have prior experience. Because unequal involvement results in unequal opportunities to exhibit skill, these are high-quality questions.

Tab. 6: Curriculum design decisions and review questions

Decision	Review question	Evidence source
Learning outcomes	Do outcomes describe observable performance at the appropriate occupational level?	Job/task analysis, standards, and practitioner review.
Content balance	Are technical foundations connected with digital, commercial, environmental, and social dimensions?	Curriculum map and assessment blueprint.
Practice sequence	Do learners progress from guided work to integrated, authentic performance?	Lesson plans, laboratory schedule, and learner portfolios.
Assessment	Does evidence demonstrate knowledge, safe practice, judgement, and communication?	Assessment tasks, rubrics, and moderation records.
Context	Are cases and data locally credible while retaining transferable principles?	Local project data, standards, and comparative cases.
Inclusion	Can all admitted learners participate meaningfully in practical and workplace learning?	Participation data, learner feedback, and accessibility review.
Renewal	Is there a defined cycle, owner, and evidence threshold for curriculum change?	Review calendar, advisory minutes, and change log.

5.8. Training infrastructure as a lifecycle responsibility

Although training infrastructure is frequently mentioned as a procurement barrier, lifecycle management is a more significant concern. Capability is not really increased by a laboratory that is set up but not kept up to date, securely overseen, or incorporated into evaluated learning. Learning outcomes and throughput—what students must accomplish, how often they must practise, how many can work safely at once, and what evidence they must produce, should be the first consideration when planning. When choosing equipment, authenticity, durability, modularity, cost, and ease of maintenance can all be balanced.

Site preparation, utilities, risk assessment, commissioning, staff training, documentation, calibration or verification, software, consumables, spare parts, preventative maintenance, fault reporting, access control, and end-of-life replacement should all be included in a lifecycle plan. Ownership needs to be made clear. Because they prepare practical work, maintain equipment condition, enforce controls, and frequently identify recurring learning or maintenance issues before they become official reports, technical workers are essential to continuity.

Utilisation is just as crucial as accessibility. Institutions may plan intensive practical blocks, employ campus facilities as living laboratories, or share costly resources across programs. Without subjecting students to risky intervention, data from operating solar systems can support teaching on performance ratios, degradation, problem detection, and energy management. Access to commercial sites through partnerships can increase authenticity, but it should be used in conjunction with a core institutional competence to ensure that learning continues even in the event that an external site is inaccessible.

Range of scenarios can be expanded via digital infrastructure. Learning platforms facilitate preparation and reflection; remote monitoring makes temporal behaviour evident; and simulation allows learners to change system size, orientation, losses, tariffs, and storage assumptions. However, the requirements for devices, connectivity, licenses, cybersecurity, and instructor competency are unique to digital access. While correctly chosen commercial tools might increase workplace relevance, open-source or institution-wide technologies may lower obstacles. Learning objectives and access sustainability should guide the decision.

5.9. Knowledge dissemination beyond formal programmes

REE's target audience is not limited to enrolled students. Decision-makers influence policy, procurement, and investment; communities engage in siting and use; financiers assess risk; journalists and civil society organisations form public perception; and system owners make decisions about operation and maintenance. Therefore, instead of just condensing a technical curriculum into shorter courses, knowledge transmission should adopt formats adapted to decisions.

Case-based executive learning can help policymakers and senior managers understand connections between technological options and institutional responsibility, risk, lifecycle cost, regulation, and procurement. Accessible content can help communities and customers understand the capabilities, limitations, safety, upkeep, and complaint procedures of the system. Technical notes, demonstrations, and communities of practice can facilitate quick updates for practitioners. Before academic and job options are set, schools can expand expectations and develop energy literacy through experiments and career exposure.

Accuracy, language, accessibility, and dialogue opportunities all affect the quality of dissemination. Although they may reach a large number of individuals, one-way awareness initiatives do not provide much insight. Stronger possibilities for sense-making are produced by facilitated demonstrations, Q&A sessions, peer learning, and follow-up materials. Digital media can broaden its audience, particularly by providing succinct visual explanations. However, it should not oversimplify safety or financial claims and should instead link to trustworthy, comprehensive counsel.

Tab. 7: Knowledge-dissemination pathways by audience

Audience	Priority knowledge	Suitable approaches
Students and prospective learners	Energy literacy, applications, programme routes, and career visibility.	School projects, laboratory visits, role-model videos, and career events.
Practitioners	Standards, innovative technologies, diagnosis, safety, and quality.	CPD, demonstrations, technical briefs, and communities of practice.
Managers and public officials	Planning, procurement, finance, risk, regulation, and oversight.	Executive short courses, cases, simulations, and peer exchange.
Communities and system users	Benefits, limitations, safe use, maintenance, rights, and responsibilities.	Local-language guides, demonstrations, facilitated dialogue, and support channels.
Educators and trainers	Technical updating, pedagogy, assessment, and inclusive facilitation.	Trainer academies, peer observation, open resources, and attachments.
Industry and professional bodies	Talent pipeline, curriculum contribution, and quality expectations.	Advisory forums, placements, joint assessment, and occupational standards.

5.10. Stakeholder responsibilities and governance

Governance that maintains accountability while allocating responsibilities is necessary for a systems approach. The government offers a supportive qualifying environment, finance indications, and coherent policies. Safety and quality standards are implemented by regulators and standards organisations. Educators create lessons, evaluate students' proficiency, and uphold academic integrity. Employers provide feedback, equipment exposure, placements, and labour market intelligence. Professional associations promote ethics, standards, and ongoing improvement. Communities and learners share their experiences and point out implementation or access issues that institutions might miss.

A renewable-energy skills council, an existing sector forum, or time-bound working groups can all be used to organise coordination. The functions—maintaining an occupational map, assessing demand, deciding on priority competencies, organising placements and sharing facilities, keeping an eye on inclusiveness, and releasing a succinct yearly skills report—are more important than the form. Data should be used to support decisions rather than the biggest organization or most conspicuous technology.

Attention must be paid to vendor influence and conflicts of interest. While equipment manufacturers and suppliers can offer useful up-to-date information, educational choices should be clear and expose students to principles that can be applied elsewhere. If programs grow more quickly than opportunities for supervision, placement capacity may also create a bottleneck. Prior to a rise in enrolment, alternatives such rotating field intensives, campus living laboratories, and simulated projects should be established.

Tab. 8: Indicative stakeholder contribution matrix

Stakeholder	Primary contribution	Accountability mechanism
Government ministries	Policy alignment, funding coordination, and national workforce intelligence.	Published priorities, budgets, and periodic skills reporting.
Education and training providers	Curriculum, delivery, assessment, learner support, and applied research.	Programme review, moderation, and graduate outcomes.
Regulators/standards bodies	Licensing, codes, safety, and quality requirements.	Transparent standards and compliance feedback.
Industry and utilities	Task intelligence, placements, equipment exposure, and practitioner input.	Defined partnership outputs and supervisor feedback.
Professional bodies	Competence standards, ethics and continuing professional development.	Credential criteria and CPD quality review.
Learners, workers, and communities	Experience of access, training, work, and project impacts.	Representative participation and responsive feedback processes.

5.11. Risks in implementation and mitigation

The same factors that make REE urgent also lead to a number of implementation risks. Enrolment may take precedence over teacher and facility capacity in a rapid expansion. Without sufficient evaluation, short courses might be promoted as career credentials. Laboratories sponsored by donors or vendors might not have operating budgets. Collaboration in the industry may rely on personal connections and vanish when employees change. It is possible to enlist students from under-represented groups without providing them with the academic, financial, or mentoring support they need to finish.

Realistic capacity planning and clear norms are the first steps toward mitigation. Program approval should confirm recurring resources, safe practical throughput, and staffing. Level, learning objectives, evaluation, and advancement should all be specified in credentials. While equipment initiatives should incorporate staff development and a total-cost-of-ownership analysis, partnerships should be institutionalised through work plans and reviews. Plans for inclusion should publish result data, not only promotional participation statistics, and address the full learner journey.

Being overly receptive to urgent projects is another concern. While operations, maintenance, grid management, and future technological requirements continue to exist, construction demand might be high yet transient. Project phases should be distinguished, and scenarios should be used in skills planning. When a specific procurement program slows down or technology changes, learners are protected by foundational and adaptable competency. This is a just-transition protection as well as an educational obligation.

5.12. A phased action agenda

Stakeholders can select key occupations, map current facilities and services, establish governance, and pinpoint urgent safety or quality shortages during the first phase, which lasts around zero to twelve months. Revision of certain practical tests shared professional information, consistent terminology, and educator updates are examples of quick actions. In order to measure future improvement, baseline indicators should also be agreed upon during this phase.

Providers can update curriculum, create stackable routes, bolster laboratories, formalise placements, and implement prior learning recognition during the second phase, which lasts one to three years. Programs for developing trainers should incorporate assessment, applied pedagogy, and technology updates. Evidence from the access baseline can be used to focus mentorship, bridging services, and scholarships. Before being expanded, early micro-credentials should be evaluated in well-defined regions.

The system can include labour-market forecasts, outcome evaluation, regional cooperation, and qualification recognition in the third phase, which lasts three to five years. The first round of evidence-based curriculum renewal should already be underway. Effective programs can develop into regional centres for trainer development, applied research, and specialist training. Stable institutional competence should replace individual projects as the primary source of long-term funding.

Tab. 9: Phased action agenda and tangible outputs

Phase	Priority actions	Tangible outputs
0–12 months	Convene stakeholders; map occupations, provision, and facilities; identify urgent gaps; establish baseline indicators.	Skills map, governance terms, facility register, priority competency profiles and baseline dashboard.
1–3 years	Revise curricula; strengthen trainers and laboratories; formalise placements; pilot stackable credentials and inclusion support.	Updated programmes, practical-assessment standards, partnership work plans, and evaluated pilots.
3–5 years	Consolidate recognition, forecasting, regional sharing, and outcome evaluation; renew curricula using evidence.	Sustained skills observatory, recognised pathways, regional provision, and outcome reports.

5.13. Overall analytical propositions

The analytical contribution is summed up in five propositions. First, the deployment of renewable energy and educational capacity are interconnected; deficiencies or weaknesses in one might lower the return on investment in the other. Second, rather than a one-time curriculum overhaul, relevance comes from feedback and renewal. Third, an integrated evaluation of knowledge, practice, and judgement is necessary for occupational competence. Fourth, inclusion must be planned to use the entire learning pathway since it has an impact on the number, calibre, and validity of the workforce. Fifth, because the technology, standards, and organisational structures of the shift will continue to evolve, flexibility is a result in and of itself.

These claims make the study's boundaries clear. The study does not assert that transition success is only determined by education. Infrastructure, market design, institutional capability, finance, and policy coherence are still crucial. Instead, education determines an actor's ability to make beneficial use of those settings, recognise issues, and gradually enhance performance. It is a necessary but insufficient condition that can be purposefully reinforced.

5.14. Evaluation design for education initiatives

Prior to delivery, an assessment design must be designed for a credible action agenda. A theory of change that connects activities and resources to learning, workplace behaviour, and transition outcomes should be the first step in the evaluation process. Investing in a PV training laboratory, for instance, is anticipated to increase opportunities for safe practice; these opportunities should enhance demonstrated commissioning and diagnostic competence; qualified graduates should transfer the practices into workplaces; and this could lead to fewer installation defects and better system availability. There are testable assumptions in each connection.

Baseline data is crucial. While providers can record staffing, operational equipment, and current completion patterns, learners' pre-course knowledge and practical performance can be evaluated. There should be multiple follow-ups: one right after training to evaluate learning, and another later to look at workplace transfer and retention. Evidence from employers or supervisors might provide context, but it should not take the place of direct evaluation since workplace ratings may reflect opportunities, organisational culture, or expectations unrelated to competence.

The scope and maturity of the effort should be reflected in the evaluation designs. Learner feedback, assessment reliability, and design validation could be the first steps in a short new course. Employer studies, graduate tracing, and cohort comparison are all useful in an established program. When possible, longitudinal, or quasi-experimental approaches can improve causal inference. Observation and qualitative interviews are still helpful in elucidating why results vary among students or locations. Since numerical participation trends could not accurately reflect the level of practical involvement or workplace experience, mixed evidence is especially crucial for inclusion.

Planning is necessary for data governance. Students should be aware of how their data will be used, personal information should be safeguarded, and reporting should not reveal small groups. Only indicators that aid in decision-making should be used. A succinct collection that covers access, capacity, competence, transfer, and system results is more beneficial than a big dashboard that providers are unable to manage. Assigning responsibilities for data collection, analysis, reporting, and reaction is necessary, and the results should be incorporated into the planned program review.

Tab. 10: Example evaluation chain for a practical solar-training initiative

Element	Example	Evidence
Inputs	Qualified trainers, safe training stations, curriculum, learner support, and industry participation.	Staff records, facility verification, and resource logs.
Activities	Guided practice, fault scenarios, project work, assessment, and workplace exposure.	Schedules, observation records, and placement logs.
Immediate outputs	Learners complete required practice and assessment.	Attendance, portfolios, and moderated assessment results.
Learning outcomes	Learners demonstrate safe commissioning, analysis, and fault diagnosis.	Pre/post-performance tasks and retained portfolios.
Transfer outcomes	Graduates apply competence consistently in real work.	Follow-up observation, supervisor input, and work records.
Transition contribution	Improved installation quality, safety, reliability, access, and workforce participation.	Quality audits, incident trends, asset data, and labour indicators.

5.15. Financing and sustainability of provision

The sustainability of education capacity is influenced by financing approaches. Although capital funding is frequently more obvious than ongoing expenditures, when budgets fail to account for consumables, maintenance, calibration, licenses, and staff development, laboratories and practical programs suffer. Therefore, a lifecycle horizon should be used in costing, and fixed, variable, and renewal costs should be distinguished. Enrolment goals must align with safe practical capacity; increasing class size without adding more stations or supervision might lower learning quality and hands-on time.

When skills are a shared enabling condition for national transition goals and when individual firms may underinvest due to labour mobility, public assistance is necessary. Employers can provide practitioners, equipment access, placements, and targeted co-financing, especially when programs address specific industry needs. In addition to access and public benefit, learner fees should be considered. When cost prevents eligible participants from priority groups or regions, scholarships or income-contingent help may be required.

The educational mission can be supported by revenue-generating activities, but it should not be distorted. Facilities can stay up to date and connect workers with practice through testing, consulting, professional courses, and applied research. To manage conflicts of interest, safeguard instructional access, and reinvest revenue, clear governance is necessary. Travel and recognition hurdles must be considered; however regional provision can enhance the use of specialised infrastructure.

People are also concerned about sustainability. Operational fragility results from relying on a single qualified teacher or technician. Establishing communities of practice, using team teaching, planning succession, and documenting practices are all important. Laboratory preparation, equipment management, placement coordination, and curriculum renewal must all be included in staff workload models. Although they are frequently less obvious than classroom interaction, these roles are crucial for dependable, secure delivery.

5.16. Transferability of the framework

At the system level, the suggested framework is purposefully generic, while at the program level, it is flexible. In solar thermal, photovoltaic, wind, bioenergy, energy efficiency, and developing technologies, its fundamental relationships—signals, curriculum, delivery, enabling circumstances, outcomes, and feedback—apply. There will be differences in the equipment, occupational norms, and competency mix. Therefore, a common quality and governance framework should be used for technology-specific design.

Cross-border transfers need caution. What is possible is shaped by the labour market structure, energy policy, certification systems, institutional resources, and language. In a huge market, a highly specialised curriculum would be viable, but it would not be appropriate in areas with few students. On the other hand, a tiny nation might benefit from common recognition and regional specialisation. Instead of dictating the same requirements, the framework starts with demand and provision mapping, which promotes this contextual judgement.

Within-country transfers are also important. While decentralised energy applications may be particularly significant in distant locations, urban institutions may offer better connectivity, employer proximity, and amenities than rural providers. Some geographical limitations can be removed by blended delivery, mobile labs, and intensive practical blocks, but each approach has an impact on quality and cost. As long as evaluation criteria are maintained, local collaborations can facilitate contextual learning and hiring.

Transferability should not be inferred from resemblance but rather assessed through adaptation. Prerequisites, practical throughput, instructor support, learner access, and employer recognition can all be evaluated through pilot delivery. By recording modifications and outcomes, the scant body of research supporting REE in developing contexts will grow, and future initiatives will be better able to differentiate crucial framework functions from locally changeable forms.

5.17. Minimum evidence package for institutional decision-making

Institutions can improve services without waiting for a flawless national dataset, but decisions should be backed by a minimal amount of evidence. An opportunity statement outlining the project, technology, or policy change that necessitates training is the first part. A learner and occupation profile that identifies potential entrants, prerequisites, goal positions, and advancement is the second. The third is a competency map that outlines the necessary performance and how it will be evaluated. A delivery-capacity assessment encompassing educators, technical staff, buildings, internet access, placements, safety, and ongoing costs is the fourth. The fifth is an inclusion assessment that determines which supports are practical and who might be left out. A monitoring strategy that connects indications to review decisions is the last element.

Assumptions are evident with this package. A proposed online course might show non-negotiable practical objectives; a donated laboratory might reveal an unsustainable maintenance burden; a proposal for a new qualification might reveal that demand is narrow enough for a micro-credential. On the other hand, the evaluation can find pre-existing modules, campus systems, or business facilities that can be merged without creating a brand-new program. Thus, there is evidence to support both investment and moderation.

Timing should be considered when making decisions. Training too early without a reliable career trajectory might disappoint students and erode trust; training too late can require projects to import limited capability. Scenario-based planning can uncover competencies that are valued across many technologies or sectors and forecast demand under various project schedules. When a particular project is delayed, fundamental electrical, mechanical, digital, safety, and project skills frequently offer resiliency.

Tab. 11: Minimum evidence package before launching or revising provision

Evidence component	Minimum content	Decision supported
Opportunity statement	Technology, policy, or project driver; timing; scale; uncertainty.	Whether action is justified and how urgent it is.
Learner/occupation profile	Target roles, entry routes, prerequisites, progression, and demand	Programme level, recruitment, and pathway design.
Competency map	Observable outcomes, standards, assessment, and role boundaries.	Curriculum scope and credential meaning.
Capacity assessment	Staff, facilities, safety, digital access, placements, and lifecycle cost.	Delivery model, cohort size, and investment.
Inclusion assessment	Financial, geographic, cultural, disability and prior-learning barriers.	Support, scheduling, access, and monitoring.

Monitoring plan	Baseline, indicators, follow-up, responsibilities, and review triggers.	Continuation, improvement, scaling, or closure.

The evidence package can enhance inter-institutional coordination when used regularly. It is simpler to find opportunities for shared delivery, gaps, and duplication when outcomes and capability are described similarly. Because resource demands are connected to evaluated learning and transition needs rather than just equipment lists, it can help improve funding submissions. It establishes a defined foundation for implementation-based learning.

6. Limitations and future research

Rather than being a systematic review or an empirical program evaluation, this work provides an integrative qualitative analysis. Evidence from well-resourced institutions cannot be blindly applied to developing contexts due to the literature's diversity in educational level, technology, geography, and research design. Any synthesis needs to be updated on a regular basis because to the speed at which skills and transition research are published. There is still a dearth of peer-reviewed data on employer demand, training capacity, graduate outcomes, and current renewable energy employment in Botswana.

Curriculum mapping, facility audits, employer and practitioner surveys, and labour demand analysis for upcoming projects should all be used in future research to create a modern Botswana skills baseline. Longitudinal assessments could be used to determine whether training enhances career advancement, installation quality, and workplace performance. The efficacy of trainer-development methods, the validity and stackability of short credentials, and gendered and geographic access should all be investigated. Where joint provision and qualification recognition are possible could be determined by comparative research throughout Southern Africa.

7. Conclusion

Since it develops the skills necessary for technology selection, implementation, governance, and sustainability, renewable energy education is essential to the transition to solar and sustainable energy. Recurring issues with curriculum integration, practical learning, instructors and infrastructure, industry alignment, inclusive access, and ongoing growth are identified by the evidence examined here. managing these problems independently results in treatments that are short-lived; managing them as a cohesive educational system strengthens the foundation for institutional learning and workforce preparedness.

Technical proficiency should be combined with digital, systems, commercial, policy, social, and adaptive competences for effective provision. It should combine industry input without compromising educational independence, differentiate learning by occupational role, employ authentic practice and assessment, and build permeable lifetime pathways. Collaboration, inclusion, quality control, and feedback are necessary for relevance and trust; they are not extras.

Transforming project goals into a coordinated capabilities agenda involving artisans, technicians, engineers, managers, public officials, educators, and communities is crucial for Botswana and similar solar-growth contexts. A practical foundation would be provided by an updated skills map, role-based competency framework, improved training infrastructure, and an evidence-based renewal cycle. Therefore, along with energy, networks, and other tangible assets, education should be designed and funded as transition infrastructure.

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