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Educational Technology for Low-Carbon, Smart Learning Environments

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Abstract

Low-carbon, intelligent learning spaces play a significant role in addressing the immediate challenge of mitigating climate change. Low-carbon strategies in educational technology are advanced not only by improving energy efficiency but also by incorporating key components such as software and data sustainability. Furthermore, pedagogical policies should consider emissions at personal, institutional, national, and global levels across multiple microservices in learning. Developing a roadmap of actions for the short-, medium-, and long-term phases is useful for enhancing institutional preparedness. This roadmap is supported by case studies across various educational sectors, facilitating effective collaboration, sound policy decisions, consistent investments, and rigorous monitoring, all crucial elements in a proactive response to climate change in education.

Keywords: *Smart learning, Educational technology, Sustainability, E-learning, Mobile learning, Green IT, Learning analytics*

1. Introduction

Smart learning environments promise advancements in educational technology—whether on a school or education system-wide scale, or even within individual lessons and study sessions. However, the integration of low-carbon forms within educational institutions remains underexplored. The development of such environments raises critical issues related to boundaries, priorities, technical challenges, methodologies, and governance practices that must be addressed to make progress.

This introduction maps the problem's dimensions and highlights the key considerations and conceptual frameworks necessary to create low-carbon, smart, digital learning technologies.

2. Educational Technology Low-Carbon Foundations

Some educational traditions aim to prepare students for sustainability-related careers (Altomonte et al., 2016). Others acknowledge that knowledge alone is insufficient to tackle sustainability issues. Educational institutions like schools and universities, therefore, aim not only to impart information but also to foster sustainable behaviours, lifestyles, and values such as environmental conservation, social equity, and economic viability. Addressing complex sustainability challenges requires systems thinking, holistic approaches, inquiry-based learning, collaboration, and community engagement—principles that are often underdeveloped in sustainability education (Higgins, 2016). The model encompasses all citizens of all ages, utilising multi-modal activities and a wide range of lifestyles and Knowledge Creation and Learning tools. When viewed broadly, EdTech also encompasses technology-assisted communication and knowledge-building modes, enabling integration of these principles. Achieving low-carbon goals is a long-term process across all facets of EdTech—such as communication, systems, and tools—that support, enable, and improve the efficiency of the educational process, foster knowledge development, promote values, and encourage engagement with sustainability. Currently, numerous smart technologies, assets, and policies aim to help educational institutions reduce their carbon footprints.

Climate science emphasises the need for significant socio-economic change and the transformation of human-inhabited systems, such as education. Energy-intensive lifestyles and high emissions permeate many areas, including production, consumption, urbanisation, and territorial development. Educational Technology presents a dual aspect: it contributes to carbon emissions primarily via energy use but also offers opportunities to mitigate its negative impacts. Hence, every educational intervention involving technology should be evaluated for its carbon footprint.

2.1. The Idea Behind Smart Learning Environments

Smart learning environments are an emerging paradigm that enables self-regulated, personalised learning through technology-integrated solutions. This comprehensive concept involves four interconnected dimensions: environment, technology, pedagogy, and the learner (Samuel Adeyelure & Mathias Kalema, 2019). The learning environment includes spaces, resources, materials, interaction, and relationships (Antonio García-Tudela et al., 2023). Pedagogy encompasses principles and methods for organising and delivering content. Technology involves hardware, software, and technological devices used to facilitate learning. The learner dimension includes aspects like digital identity. To meet local needs and expectations, regional and contextual adaptations are essential.

Sustainability in smart learning environments aims to minimise negative impacts on the environment, society, and the economy, while fostering resilience across these areas. The educational technology cycle integrates hardware, infrastructure, software, pedagogy, assessment, and content—sustainability must be considered at each point. Smart learning environments can exist without technology, so sustainability considerations should guide the use and practices of technological tools.

2.2. The EdTech Carbon Footprint and Life-Cycle

The carbon footprint of educational technology (EdTech) is typically assessed through comprehensive life-cycle analysis (LCA). This approach considers all relevant emissions—from raw material extraction, manufacturing, transportation, distribution, consumption, reuse, to disposal or recycling—covering each step of the product’s life cycle. Ideally, an overall calculation includes all costs associated with EdTech, from raw material extraction through end-of-life, providing a fair estimate of its total carbon footprint relative to other materials, goods, or services.

A useful model commonly used for related topics categorizes an item's carbon footprint into three scopes: Scope 1, the direct carbon emissions from production or origin; Scope 2, the indirect emissions related to provision, supply, delivery, or logistics; and Scope 3, the overall residual carbon footprint, which involves estimating the entire life cycle of the item, including flows related to returns and re-manufacturing. Using this framework, various EdTech products—such as devices, textbooks, and learning management systems—can be traced back to a specific educational organisation, enabling estimation of their total carbon footprint associated with that organisation (Hill & Fülöp, 2020).

3. Principles of Designing Low-Carbon Smart Learning.

Smart Learning Environments (SLEs), which integrate information and communication technologies (ICT), enable real-time interaction, anytime, anywhere access, and involve individual or group activities. SLEs exemplify strategies that enhance effective, low-carbon learning while promoting sustainability.

Components of Smart Learning Environments include people, data, processes, technology, and digital content within personal, portable, and physical spaces. SLE practices promote interaction and effective teamwork among learners, teachers, and stakeholders. Personal roles in scaffolding, articulating, sharing, reflecting, and transferring vary, while collective involvement enriches the learning experience.

The interoperability aspect emphasises that, to develop low-carbon SLE systems, interoperability among smart learning tools and digital spaces must be promoted. Being able to access content and services seamlessly across different system elements fosters communication and cooperation, while also capturing changes in learner interactions and activities.

Smart Learning Systems actively support learners in achieving their goals by proactively tailoring content to their needs. This proactive guidance relies on various feedback mechanisms and is further enhanced across different roles, contexts, and environments. The framework presents low-carbon strategies as a defined process, with carbon considerations serving as pedagogical directives that can be optimised using data collected in various ways (Altomonte et al., 2016).

3.1. Power-Saving Hardware and Infrastructure.

Using energy-efficient hardware and infrastructure is central to reducing energy consumption and greenhouse gases (Stokes, 2009). Studies report that up to two-thirds of the energy used by PCs and monitors is wasted when they are turned on but not in use. The U.S. Department of Energy reports that the average annual energy consumption of a PC and monitor is 600 kWh. The need for energy-efficient solutions is especially urgent in states like New York, where electricity prices are among the highest. Green IT is a top strategic priority, emphasising smaller, faster, and more efficient electronics. Many educational institutions are developing strategic plans to reduce energy use, aiming to meet sustainability goals, lower their carbon footprint, and improve operational efficiency.

3.2. Carbon Reduction Cloud and Edge Computing Strategies.

Local energy footprints are minimised through cloud computing, which relies on data centres rather than local hardware, thereby reducing hardware use and energy consumption (Mallikharjuna Rao et al., 2012). Decision-making around cloud computing significantly impacts energy use and environmental sustainability (Li Yang et al., 2018). Since device usage varies with computation volume and data transfer across paradigms, reducing local device deployment—by switching to more efficient service models—can lower environmental impact. Strategies include processing only local data and minimising data exchange between cloud and local systems, which are crucial for lowering the environmental footprint and optimising workload deployment.

3.3. Green Software Design and Accessibility.

Low-carbon smart learning environment educational technologies should consider their possible ecological effects. Designs of software solutions must, however, be highly operationally efficient and modular, and must comply with accessible-technology design. A smaller codebase yields more efficient algorithms and, consequently, lower energy consumption (Moro et al., 2023). Moreover, software design ought to be interoperable and microservice-based, and to encourage reparability, upgradability, and the reuse of refurbished hardware. The Web Content Accessibility Guidelines (WCAG), Accessible Rich Internet Applications (ARIA), and the Authoring Tool Accessibility Guidelines (ATAG) are standards that can improve compliance with the principles of inclusive design.

3.4. Implications for Data Management, Privacy and Energy.

Data minimisation is the principle of avoiding the collection of redundant data that cannot be used for a specific purpose. Users should receive notifications about what is being collected, so they remain clear even after observing the collection and termination of unwarranted information (Villegas-CH et al., 2019). Retention period refers to the length of time data is stored. The risk of data leakage is directly related to the time of storage. Data Encryption safeguarding practice refers to encrypting digital data so that only authorised persons with the key can read and access the information. Energy consumption has been veiled by storage and processing. The growing statistics have unleashed soaring demand, with a call for both effective conversions and per-capita cuts in earnest (Corrin, 2021).

4. Pedagogical models of low-carbon environments.

Educational technology is instrumental in encouraging and attracting students to an evolving, personalised learning space that can easily address learners' needs. A good low-carbon learning environment may be effective in triggering learning, as it can enhance participation in the learning process at the same or even reduced carbon cost. There are other new educational models, such as E-learning 2.0 and collaborative learning models, that have been developed and have given an impetus to the use of sustainable, low-carbon educational technology by both teachers and learners. These models are useful for creating sustainable education systems that benefit society as a whole.

Three pedagogical models can be used to understand low-carbon smart learning environments. The Low-Carbon Education Student Model offers a lasting starting point for cultivating low-carbon and ecological consciousness among students, enabling them to collaborate to build a more sustainable low-carbon society. The Low-Carbon Learning Community Model promotes collective learning, whereby students can actively share knowledge across various fields to gain a holistic view of low-carbon education. The Collaborative Learning Model establishes each student's collaborative potential across six levels, enabling teachers to form collaborative teams based on members' levels of collaboration and to enhance student interaction actively. The models prove helpful in marketing environmentally friendly learning technology to create a low-carbon learning environment (de Freitas et al., 2008; Higgins, 2016).

4.1. Remote and Hybrid Learning as Mechanisms of Reduction of Emissions.

The COVID-19 pandemic led to remote and hybrid models of learning. These approaches are among the most effective for reducing carbon emissions, yet their prevalence raises questions of equity (Nehal Hasnine et al., 2022). Education was disrupted in most high- and middle-income countries because of physical school closures. Many educators and learners have used online or hybrid learning to continue educational processes and knowledge acquisition in basic education; higher education institutions have shifted to fully online or hybrid education to accompany the gradual development and implementation of EdTech approaches. A course is considered hybrid when a percentage of it is delivered online, so the instructor and all students do not have to be in the same location at all times during the course.

4.2. Individualised and Customised Learning at Low Carbon Cost.

Individualised and adjustable learning is a good option in the pedagogical approach, as it would imply minimal carbon cost. When well implemented, they may also result in significant footprint cuts. Adaptive and personalised learning systems can significantly enhance the effectiveness of the learning process. Adaptive learning provides personalised avenues for learners, automatically and continuously customising content, activities, feedback, and other elements to the changing needs of individual learners based on their interactions. Personalisation, however, is based on processes and profiles developed for an individual learner at the earliest stage. Data on the learners is collected and, with their permission, used to build learning paths and support that best fit their needs. There are various algorithms and decision trees that could be applied to analyse the information collection. Only one student model and individual options can also be used. Online tests can be created and administered to obtain data on students' knowledge and skills, and students can be federated into homogeneous groups based on their profiles to create personalised e-tutoring systems (Coffin, Murray & Perez, 2015). A lower footprint is achieved by adaptive and personalised learning systems that flexibly reuse content, depending on the specific multi-dimensional learning object. Recommendations and support for students on the platforms are also a high priority in both adaptive and personalised learning activities, provided their informational governance and capacity allow them to do so. Online tests do restrict the volume of content that can be recycled; however, broadly available low-footprint materials like OER, named Lemm Learning Objects (LLO) or Lemm and Performance As A Service (PaaS), can assist in the flexibility and customisation of the learning procedure and the assessment process whenever traditional LLO fails to work.

4.3. Student-Centred Learning to Sustainability.

Learner-centred methods enable active learning and nurture self-regulation skills by giving learners greater control over their learning process, allowing them to decide what to study, when to study, and how to demonstrate their learning, in line with Knowles's pedagogical theory. They help learners acquire competence by providing instructions on what to use and how to use it to complete their planning. These strategies may be strengthened when learning analytics is used to provide feedback on students' progress towards learning goals, making students more aware of their performance and prompting them to further self-regulate their learning. Moreover, they reinforce the dependence between carbon reduction and student learning because the pedagogical adjustments required to implement them are not only compatible with low-carbon learning but also fit within the technology of the digital learning pathway, as the method is restricted to (Altomonte et al., 2016).

5. Evaluation and Measurement

The Edinburgh Process shortened the time teachers needed to examine learning outcomes (J. Lister, 2017) and to explore pedagogy and technology. New learning indicators were suggested that place primary emphasis on engagement rather than attainment and make evaluation easier across different situations. The agile working style was designed around smart learning environments that required minimal preparation. Educational technology is most effective and beneficial when the point of computer intrusion is everywhere: in a learning zone specifically assigned to the task, in room-to-room transit, or in a place that accompanies the learner.

5.1. Educational Technology Carbon Accounting.

Information and Communication Technologies (ICT) have, in recent decades, increased the demand for and consumption of energy. This growth leads to environmental, financial, and social issues due to the adverse effects of such technologies (C. Cordero et al., 2020). Educational Technologies (ETs) fall under the umbrella of ICTs, and as a result, their use is rapidly increasing, particularly due to the ongoing COVID-19 pandemic. The primary objective of accountability for educational technologies on carbon, therefore, is to quantify their carbon footprint using a homogeneous approach to educate and raise awareness of the inherent issues arising from the unremitting increase in their use. The Carbon emissions can be calculated with the help of various organisational frameworks, standards, and tools; however, three of them should be regarded as the most interesting: GHG Protocol by World Resources Institute, PAS 2050:2011 and ISO 14067:2018 can be utilised to understand the overall climate impact of Educational Technologies during their entire life cycle. They allow measurement of carbon emissions across 15 different scopes. Four of those scopes, which are commonly referred to as Scope 1 to 3, and at the same time categorise Product, therefore, serve and supplement the final accounting process. Scope 1 is associated with the emissions that are under direct control, e.g., gasoline emissions in a vehicle travelling to deliver a polluting course. Scope 2 understands emissions obtained under the commercial arrangements in which the supply of an activity (e.g. electricity packaging) is done. Scope 3 includes the remaining indirect emissions not captured in Scope 2, which are byproducts of the activity being measured. Under the Educational Technologies umbrella, thus, a particular technology may have three categories of transactions. The former refers to the purchase, use, and/or disposal of any electronic device at the expense of an educational activity. The second is the subscription to and use of a cloud-based Educational Technology service (cloud infrastructure). The final one is the implementation, entrepreneurship, return, the compliance and/or cancellation of any technological service that traverses through a particular technological platform. These three scopes can show the actual impact of a technology on ultimate carbon emissions and permits, in the context of carbon accounting.

5.2. Learning Outcomes, Engagement and Sustainability Measures.

To gain better insight into how educational technology might affect carbon footprints or reduce them, educational institutions are increasingly seeking methods to quantify its effects on learning outcomes and engagement (Isaias & Issa, 2013). Other indicators most commonly used to measure the financing effect of educational technology are generic exposure and engagement indicators (Altomonte et al., 2016). Such structures have been developed by many institutions and ministries that have studied technology adoption for over 35 years. Stakeholders, however, face both conscious and practical challenges in adopting such measures, while recently funded educational technology is under review.

How educational technology-related policies, investments, and practices can help achieve decarbonization, measure learning outcomes, and control engagement levels. First, gathering more detailed information every so often on the participation of education technology in contributing to learning outcome-related questions, such as career- and credentialing-related questions, course completion-relationships and assessment-success related measures, will yield a decrease in confusion as to the use of the money. Also, applying the same periodic collection with the view of comprehending the development of the policy-investment, practice-impacts on the various elements of engagement-frequency of access to a system, percentage of materials utilised, etc., enlightens an engagement circumstance and expression regarding the policy-investment-device. Lastly, the indicators can also estimate the sustainability and accessibility of the current technology on campus, as well as the amount of carbon avoided by using the device.

6. Policy, Governance and Institutional Readiness.

To stay competitive in the global marketplace, 21st-century economies are increasingly allocating resources to transform their educational systems, enhancing their capacity to develop the knowledge and skills that the workforce and citizenry require. These reforms centre on innovation, to develop knowledge and skills through appropriate information and communication technology (ICT) (CHI, 2018). In particular, the learners are to adapt to the rapidly changing situation and respond accordingly, pursue new concepts rather than merely rely on prior knowledge, and apply advanced processes of innovative thinking. ICT is an important facilitator of the smooth development of those qualities and thus is essential to education reforms worldwide.

The deployment of educational technology (edtech) will involve collaboration among many stakeholders to govern it and develop policies (including governmental authorities, learning institutions, edtech developers, teachers, learners, and parents) (Samuel Adeyelure & Mathias Kalema, 2019). These stakeholders have complex relationships in governing and hold different positions regarding the institutional readiness of educational systems for edtech. The governing structures, i.e., the rigidity of coverage and the pace of government intervention, will thus be structured to accommodate the differences (Chang & Uden, 2008). Governments should not merely control the current enterprise systematically but also carefully promote the transition to the new enterprise.

The edtech deployment should be governed within existing governance frameworks, including councils and committees, and aligned with government policies and strategies for the overall education sector. Historically, educational systems have had a high level of freedom from government interference. Most developed education systems, particularly at the higher education level, rely on flexible business models to compete in the market. Many such systems are not actually open source. Nevertheless, it is increasingly recognised in certain education systems that functional collaboration among educational institutions is necessary to deliver learning sustainably. This is why one should consider new business models that meet these requirements and facilitate information exchange.

Arrangements, structures, and stakeholders involved also differ in other ways. The owners, founders, chairpersons, boards of directors, government regulatory bodies, and certification bodies are among the stakeholders in the traditional office-college industry, with diverse interests.

The variety of actors to this extent results in intricate governing relationships and positions.

6.1. Green IT Policies and Strategic Investments.

The development of strategic investments in educational technologies aligned with green IT policies would further drive institutional changes towards low-carbon smart learning environments. This type of investment may also centre on selection criteria that emphasise minimising the carbon footprint over the life cycle, the development and dissemination of carbon-reduction technology, or the enrichment of citizen competence as a cross-practice investment. Furthermore, organisational leaders may consider ways to transform governance systems and funding modalities to accommodate e-learning portfolios, internal e-learning objective-priority systems, and institutional strategic plans (Sakirin, 2014). Creating an organisational or institutional electronic portfolio of e-learning can enable the administration to demonstrate connections to other expectations regarding technology and to recognise parallel stakeholder roles, duties, and pathways of influence. Capstone anticipations of e-learning subsets and affinities among them can be described using associated e-learning objectives that can describe rationales of readiness, connect various investment paths within a more consistent overarching e-learning strategy, and explain interdependencies of priorities between cluster portfolios without disincentivising commitment of wider stakeholders to green or low-carbon goals (Issa et al., 2011).

6.2. Change Management and Stakeholder Roles.

The development of educational technology to facilitate low-carbon, smart learning environments requires a reconfiguration of stakeholder roles. This paper aims to conduct a multi-actor analysis of institutions of higher education in Denmark, Iceland and Norway, which suggests that three key actors (Senior Managers, Educational Technologists, and Academic Staff) ought to concentrate on pathway or port-of-entry models to match three adoption approaches: One-off Initiatives, Project-driven Transformations, or Strategic Change. The paths help educational technology stakeholders understand where their institutions are at the moment.

The current trend in educational technology offers possibilities for low-carbon, intelligent solutions. However, policy and governance shifts, as well as institutional preparedness, are yet to be transformed. Such technologies require institutional mechanisms for adoption, and strategic investments aligned with the guidelines of green information technology (IT), green information and communication technology (ICT), and new instructional frameworks are important parameters.

Senior Management is a significant institutional-level stakeholder group and includes University and Faculty Leaders, Deans, Vice-Presidents, Presidents, Pro-Vice-Chancellors, Heads of Department, Rectors, Directors, Registrars, and Owners. The Senior Managers should develop investment strategies to fund low-carbon and smart educational technology, thereby dictating the direction of their low-carbon strategies. They determine whether to prioritise low-carbon, intelligent educational technology and allocate budgets to the relevant departments.

Educational Technologists are at a significant institutional cross-institutional level. Learning Designers, Educational Developers, Instructional Design Specialists, Educational Technicians, and other individuals who describe educational technology applications fall into this category. It is the mandate of Educational Technologists to put into perspective critical spheres of the institution for consideration, and, as such, to inform the nature of change and recommend appropriate pedagogical methodologies to the Senior Management. In this regard, the prevalent documentation has been on sustainable and/or alternative pedagogical practices and methods. Educational Technologists can have a great impact on various parts of educational technology in the institution, depending on the level of change they seek, such as One-off Initiatives, Project-driven Transformation, or Strategic Change.

The last group of participants on the institutional level is Academic Staff. The title Teacher, Educator, or Academic may also be used by Academic Staff, depending on the institution's nomenclature, and encompasses lecturers, professors, and other like-minded people engaged in teaching practice. At this point, the disciplinary leadership of these professionals is useful in laying the groundwork for educational change. By making contact with the Senior Management, Academic Staff can promote the low-carbon and/or smart educational technology. They can also get some guidance on a condition that only low-carbon and/or smart solutions are obtained in exchange for institutional support for such technologies. This occurs because most of them strive to achieve their goals regardless of the ethical consequences, resulting in significant harm to others. This is because most of them are willing to reach their ambitions at all costs, irrespective of the ethical implications, hence causing great harm to others.

6.3. Standards, Compliance and Interoperability.

Standards compliance is a vital part of any technology's description. The design, development, interoperability, and management of educational technology systems are supported by several standards, guidelines, and frameworks. Once aware of most of these standards, institutions can communicate them to their stakeholders, enabling stakeholders to shift to lower-carbon educational technology easily.

The EN ISO 9241-210 (2010, 2019) standard, developed by the European Committee for Standardisation, is used to assist in the development of Interactive Systems in the Learning Environment. This standard provides an outline for enhancing learners' experiences and minimising cognitive load by designing them to be interactive and user-friendly. As a result, the low-carbon objective of learning settings is provided indirectly. The 9241-210 standard is complemented by the ISO/IEC 27555 (2022) measurement framework, which determines the maturity level of a human-centred approach to enhance education and knowledge acquisition. Lack of Approach is the first maturity condition, meaning there is little or no attention to the transfer of knowledge and to how the selected method and learning context influence the overall educational experience. The second maturity state is the Ad-hoc state, which analyses teaching and learning processes and understands that they are not transactional. Such a system may not place much emphasis on the environment or other factors during the learning activity. The shift to the fourth, fifth, or even better, sixth maturity level would make the educational experience more enriching, particularly by focusing on low-carbon practices.

The concept of an interoperable educational environment can be defined as a network of systems or the smooth integration of various services. This enables the practice of choice-based learning environments, as every aspect selected or suggested conforms to desirable compliance standards. Specifically, Augmented Reality (AR) offers visualisation options that go beyond the constraints of 2D still images and 3D models.

The ISO 24751 (2008) Adaptive Technology and Equivalent Access to Learning Resources facilitates the two-way flow of information regarding the components of learning resources. This key-based adaptation is synonymous with the machine-learning theory of one-to-one mapping. It also includes a publication that proposes the so-called CLAROE (content, learning activity, resource, organism entity) model for describing learning resources. CLAROE is based on the LOM model because the LOM description can be directly derived from it. Certain OER disciplines have significantly more instructional content and learning materials that are available, which is also a challenge. The Open Educational Resource (OER) trend aims to provide greater and broader access to knowledge, but there is no similar movement regarding the environmentally friendly use of Instructional Content. The following education system aligns with the dual OER idea, maintaining higher education standards without causing instructional content or systemic restructuring that would further worsen the environment (Rey-Lopez et al., 2008).

The education sector has yet to establish a flexible, unobtrusive, and generally acceptable solution for e-Assessment and related e-learning systems because of the nature and structure of e-Assessment forms. Essentially, the availability of standard conformity or a universal standard that drives the configuration and deployment of system solution architecture is considered critical to e-learning and e-assessment systems (AL-Smadi et al., 2009).

7. Case Studies and Best Practices.

Education is the most important factor in curbing carbon emissions, especially in transport. An educational network focused on low-carbon practices at a secondary school was implemented in various ways. The gadgets included PCs, laptops, tablets, phones, microwaves, interactive screens, and printers. Emissions directly related to teaching and learning activities during the academic year were reduced by nearly half compared with four years preceding the implementation of the solutions. It was found that half of the overall cut could be attributed to travel savings, which were on course to meet the sector's overall targets. In 2018, the University of X implemented a per-charge carbon-emission indicator to quantify the electricity consumption of devices deployed on a state-of-the-art campus with smart energy management solutions. Device charging is done outside business hours, where possible, to improve energy efficiency (Jewitt et al., 2010).

An independent reviewer also undertook a review commissioned by the UK Joint Information Systems Committee to determine the sustainability implications of open educational resources and virtual laboratories. Although these are important tools for facilitating remote access to educational practices, they have been found to increase resource requirements, increase power, bandwidth, and storage consumption at the outset, and increase carbon emissions. They further found in their analysis that the net effect of replacing physical textbooks with digital ones, even amid extensive international growth, can be trivial (Lewin et al., 2008).

7.1. Case Study A: Primary School Education in a Low-Carbon School Network.

Low-carbon schools contribute to high-quality education for students. Low-carbon school networks can promote quality teaching and learning in developing countries and regions. These delivery systems are based on the SAT and portable digital tablets in South Africa. Zibonele Primary School in the Western Cape Province offers education and learning with a low carbon footprint due to a comprehensive range of digital connections (Lotz-Sisitka, 2011). The technologies used in Zibonele, such as photovoltaics, solar water heating, biogas, and wind turbines, are renewable technologies that address energy, curriculum, health, and safety issues. The satellite-based and portable delivery systems are compliant with environmental policies.

The Zibonele site has a satellite dish stand that facilitates the delivery of content via mobile digital teachers. Digital access and curriculum provision are made broad through the use of trained tutors. Digital delivery techniques enhance both sustainability and learning. Portable delivery systems improve access, equity, and technology transfer in curriculum delivery, especially in practical subjects that involve physical participation. Low-carbon prioritisation of intensive curriculum delivery is achieved through a Workshop mixed-technology, blended-learning, flexible-pedagogy policy.

7.2. Case Study B: Smart Energy Management in Higher Education Campus.

The Smart Energy Management System (SEMS) presented in this case study has been introduced at the Universiti Tun Hussein Onn Malaysia. Its range of sensors is quite broad, enabling the collection of fine-grained information on energy and water consumption, as well as weather conditions, independent of human activity (CORNO et al., 2017). Then, a cloud environment compatible with Big Data and the Internet of Things was deployed to enable real-time visualisation and support analytics. An energy model calibrated to a zero-energy building reference standard clearly tracks general improvements. Indicators that measure resource conservation rates and occupancy levels help raise awareness of energy-saving measures, whereas user-friendly feedback systems can report on facilities and needs in academic areas (Villegas-CH et al., 2019).

The large collection of sensors is typically impractical to deploy across large geographic areas, and most of the required algorithms can be applied to other resources; hence, the energy-management toolkit has potential applicability to campuses, districts, or cities with existing smart metering that can supply periodic time-series data to a central platform.

7.3. Case Study C: Virtual Laboratories and Open Educational Resources.

Virtual laboratories and open educational resources (OER) are affordable, convenient alternatives to conventional labs, expanding access to STEM education. Laboratory experiments, such as those conducted in LabVIEW, can also be used in engineering education, allowing students to perform practical work digitally. Research shows that virtual labs enhance student learning and satisfaction, providing a flexible, interactive learning environment. Online-based resources combined with face-to-face teaching also work well as hybrid models. These inventions promote unconventional learning methods in higher-level engineering.

The concept of remote laboratory platforms makes practical experimentation in STEM education more accessible by providing 24-hour access and enhancing the learning experience. The remote laboratories differ in that they use real equipment operated remotely, whereas virtual laboratories operate entirely through simulation. Most currently implemented remote labs use cheap, open-source software and single-board computers like Raspberry Pi and Arduino microcontrollers to control equipment, but not open-source hardware. A modular design with electronic cards and a motherboard. The Laborem project at the University Institute of Bayonne provides a low-cost, scalable remote electronics platform based on open-source hardware and software. It offers a cheaper alternative to more costly solutions, such as VISIR, enabling the student to design circuits using robots and cameras, thereby increasing motivation and immersion. (Augusto Pereira et al., 2018)

8. Implementation Roadmap

The educational goals and interventions to be implemented at the elementary and secondary levels will be set against the backdrop of current developments in educational technology. Issues that require greater attention, such as human resource development, teaching materials, capital investments and other infrastructure, and government policy adjustments, are outlined. An effective implementation plan that addresses these issues is provided. The model of educational technology proliferation, which entails four major initiatives, is described to enable IT development within educational institutions and to assist in the realisation of pilot projects in secondary education. It is proposed to implement a follow-up computerisation program across primary and higher education, thereby making educational technology available throughout the whole district of Tororo (Samuel Adeyelure & Mathias Kalema, 2019). The activities in these schools will serve as a wise large-scale experiment for the government of Uganda, which plans to offer similar facilities in all primary and secondary schools in the country. Emergency interventions, which include wiring government buildings and community facilities, and more intensive efforts to streamline technology flows between the education and private sectors, are also considered beneficial.

It is now envisioned to pay more emphasis on handling policy issues and educational content. There are also long-term investment initiatives to support educational technology, including establishing an inclusive policy, developing a committee, and utilising government revenue. Priorities investment programs, including the incorporation of future information technology in education (preference constraints that allow increased compliance and involvement of the masses) and the massive integration of ICT, are also covered (CHI, 2018).

8.1. Short-Term Interventions

The following short-term interventions can be considered by institutions or laboratories that may be interested in placing low-carbon educational technologies on their own initiative or in participating in strategic and coordinated programmes at the local, national, or global levels. They ought to delegate it to a specific person, group, or organisation. Periodic review of progress can establish short-term, quantifiable goals and provide a basis for periodically reporting the impacts of individual actions and general initiatives on carbon reduction.

Implement an investment policy that focuses on low-carbon, intelligent educational technologies for new purchases, upgrades, or replacements, to be developed over time as inventory and institutional experience increase. The low-carbon focus should be maintained by integrating these technologies with existing services, verifying them using carbon-accounting tools, and regularly comparing them with conventional alternatives.

Identify buy-in options with suppliers and service providers to have first-hand access to their stocks of assets registered under recognised carbon-checking instruments. Continuing relations allow verification of carbon-embedded estimates and operational estimates for additional new services and equipment.

When seconding or cross-appointing staff in the early stages of their careers, involve them in carbon-conscious teaching practices, research or curriculum design. Provide a specific time to practice with the tools, equipment, and techniques provided by low-carbon education.

8.2. Medium-Term Initiatives

The South-East European Network of Professional Development of Educators (SEENPEDE) focuses on developing online 21st-century artistic works through the collaboration of art and music educators in Hungary, Croatia, Romania, and Serbia. Even though these nations might have different methods for training in digital art, greater similarity in understanding key concepts would greatly help with effective coordination, especially in the arts and culture field. The SEENPEDE initiative advocates project-based learning (PBL), which requires students to build their knowledge of a given subject by completing a project. Within a PBL model, as in Hungary's modern National Core Curriculum, the instructor becomes less the primary source of information and more the architect of the learning process for a particular topic. With the added assistance of cloud computing technologies, a few of the Hungarian partners create the tools, methods, and interfaces that enable successful collaborative artistry in a digital, project-based setting. Thus, solutions can be easily specified with respect to architectural solutions in terms of integrating low-carbon educational technology in the said activities (Mónus & Lechner, 2017) ; (Salomón et al., 2012).

8.3. Strategic Transformation in the Long-Term.

The strategic vision of the low-carbon, smart learning environment incorporates the frontiers of education by emphasising connected, collaborative, open, flexible, lifelong and ubiquitous learning. In line with and extending the vision published in 2021 by UNESCO, the approach represents dynamic governance and continued improvement to support knowledge in achieving sustainable development through Education for Sustainable Development and Education for Global Citizenship (Brown et al., 2019). It focuses on transforming learning and education (through the interconnectedness of people, ideas, and technology); fostering collaborative and participative processes; breaking down traditional obstacles; and making education a change agent towards sustainability. The suggested strategy is a mixture of high- and low-tech resources to reach and engage young people. Comparing progress towards learning, social, environmental, and economic performance provides a multifaceted perspective on adapting to a changing environment. It involves collaborative work with a variety of actors, such as government, society, business, and science, and entails tolerating differences in context, purpose, and speed. The strategy involves interaction with Start 2.0, a multi-party collaboration programme at the community level. Start 2.0 illuminates the sustenance dilemmas of societal transformation, fosters educational aspirations, and promotes engagement through flexible, learner-based, and outcome-driven processes that enable boundless adaptation to evolving situations and unpredictability. Korea had been engaged in a transition to a low-carbon, green economy before the 2008 financial crisis. This desire remains, yet methods and technologies have evolved significantly; thus, another revision of the education, motivation, and collaboration elements is long overdue. The strategy promotes the transition from less traditional, supply-based methods to social-innovation-based, user-centred, and co-designed processes. The use of collaborative, project-based tasks provides avenues for participatory learning beyond traditional approaches.

9. Risks, Challenges, and Mitigation.

There are significant risks and challenges associated with educational technology initiatives that can impede the implementation, proliferation, and sustainability of the system (Niederhauser et al., 2018). Numerous factors influence the integration of technology into teaching and learning, and shortcomings in pedagogy, infrastructure, and hardware limit the scope and intended outcomes. It is necessary to adopt a multi-layered approach that addresses multiple constraints to ensure greater technological reach and impact. As a result, effective integration remains hard to achieve. It is necessary to gain deeper insight into teachers and settings. The technology being used and the intentional pursuit of policy and instructional strategies beyond access to technology, its funding, and educator development. Emerging educational technologies offer distinct educational possibilities, but they also raise serious concerns about learning equity, particularly for remote learners and low-income and vulnerable learners. The most significant educational equity problem is unequal access, which may be further exacerbated by the continued development of the EdTech industry, the polarisation of educational infrastructure, the increased use of physical and distance education as pedagogical means, and unequal access to high-performance and low-carbon learning resources.

9.1. Technical and Digital Divide Issues.

The technical and digital divide continues to be a problem for many less fortunate institutions in implementing state-of-the-art educational technology and in the shift to integrated, low-carbon smart learning facilities. Over the past ten years, numerous nations have made their environmental goals more focused on reaching net-zero emissions by 2050 or 2060, and expedited the integration of meaningful digital educational technology at all education levels in a move to attain high-quality and equitable education. However, disadvantaged institutions, in particular K-12 schools, are still grappling with how to effectively incorporate digital tools into the pedagogical process due to limited funding; a lack of devices, or devices that are inadequate; insufficient time and professional development; and a lack of technical support. Such concerns should be addressed to approach future challenges (Orta, 2019) successfully.

9.2. Supplier Reliance and Supply Chain Strength.

The absence of resilience in the educational technology supply chain creates a heavy reliance on a single vendor or a small group of vendors. Where possibilities can be exploited to pursue a solution that involves a single vendor, that must come before making investments to minimise the risk involved in that solution, such an analysis of the vendor, its market, and the circumstances will help determine when the market remains sufficiently interested in using a single or limited vendor, and when other important benefits will counterbalance the dangers of vendor lock-in.

Risk mitigation should then be concerned with the definition of the appropriate risk reduction strategies to be implemented should one of the preferred vendor is transferring to lock-in position, delineation of actions that can be taken independent or dependent on external, and then processes to identify and implement the strategies that are about to be executed home or already under-use (Moro et al., 2023).

9.3. Privacy, security and Ethical considerations.

An educational system based on low-carbon principles that serves a wide range of students and enables them to reach their full potential must adopt educational technologies that offset its carbon emissions. In that case, the carbon footprint of learning environments can be reduced through the selection and design of hardware and software, pedagogisation, and assurance and assessment practices. These practices encompass utilisation of technologies that require less or more efficient travelling; low-energy consuming technologies (Maguire, 2017) or renewable technologies; curriculum that facilitates diversified learning and replaces or downsides unavoidably high-footprint physical-experience or physical-travel-delivered training; reduction techniques of energy moving between and accompanying management of terminals, joining with reduction of times of access (the SLOC metric). Education technology oriented towards low-carbon facilities is more likely to promote emerging skills than to develop high-footprint practices (Borcea-Pfitzmann & Stange, 2007). Active learning that has a high propensity of sharing fully (International and Machine Learning styles) or partially among students is associated with the emergence of centralised training to impart the varied knowledge needed to use the low-carbon facilities.

10. Conclusion

Beyond carbon accounting, the United Nations Development Programme (UNDP) also advocates a systematic approach to sustainable development that emphasises learning in a low-carbon manner. The analysis of policy and curriculum documents to aid in educational development, along with the three case studies of low-carbon educational technology interventions, has several implications for research and practice. The process of assessing the criteria and elements of sustainability pertinent at various levels is suggested to encompass an extensive overview of green ICT platforms and energy conservation evaluation criteria. Additional field research and a literature review of cloud-based learning service and infrastructure models that have a less pronounced environmental and climate-change impact than traditional models are recommended. The possibility of leading educational recovery after learning disruptions resulting from the COVID-19 pandemic and the shift towards energy conservation and sustainability, with the help of educational technology, is emphasised. The Universal Declaration of Human Rights aims to promote quality education in line with the principle of sustainable development, as a declaration for all nations. Latest news from the United Nations Environment Programme underscores the extreme urgency of efforts to achieve major carbon emission reductions, in line with educational establishments pursuing a connected society through smart education.

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