Educational Technology as a Catalyst for Sustainable Energy Training: The Strategic Framework of the Portuguese Center of Vocational Excellence

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Article

Educational Technology as a Catalyst for Sustainable Energy Training: The Strategic Framework of the Portuguese Center of Vocational Excellence

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Abstract

This article presents the design and implementation of a strategic sustainability framework for the Portuguese Center of Vocational Excellence (CoVE) in Sustainable Energy (SECoVE), coordinated by the Polytechnic Institute of Porto. The initiative aims to strengthen regional capacity and interinstitutional cooperation among universities, vocational education providers, industry, and public actors, promoting green skills, applied innovation, and collaborative governance within the energy transition ecosystem. Based on an evidence-based situational and ecosystem analysis, including SWOT analysis and stakeholder mapping, the study identifies key internal and external drivers shaping the CoVE's strategic development and its contribution to sustainable regional transformation. A distinctive feature of SECoVE is the integration of educational and immersive technologies, such as Virtual Reality (VR), Augmented Reality (AR), and interactive digital learning environments, supporting the development of high-quality, technology-enhanced educational programs in sustainable energy. The proposed strategic framework defines four interrelated objectives: strengthening technical and green qualifications aligned with national and European agendas; establishing SECoVE as a hub for applied research and innovation; expanding strategic partnerships among education, industry, and public actors; and ensuring a diversified and resilient financial structure. The study contributes to the academic debate on the Centers of Vocational Excellence as catalysts for the green and digital transitions.

Keywords: vocational excellence; sustainable energy; educational technology; green skills; innovation ecosystems; virtual reality; applied research; regional development; digital transition; technical education

1. Introduction

The transition towards sustainable energy systems is widely recognized as a central pillar of global climate action and socio-economic transformation. Within the European Union, policy frameworks such as the European Green Deal, the REPowerEU Plan, and the EU Skills Agenda emphasize the critical importance of developing green and digital competencies to support the decarbonization of energy systems while fostering competitiveness, social inclusion, and regional resilience. In this context, education and training systems, particularly vocational education and training (VET), play a strategic role in equipping current and future professionals with the skills required to operate, maintain, and innovate within increasingly complex and technology-intensive energy ecosystems.

Digital technologies have emerged as key enablers of this transformation, not only within energy systems themselves but also in the processes through which skills and competencies are developed. Virtual reality (VR) and immersive learning environments have been shown to enhance experiential learning, improve safety in high-risk technical training, and support the acquisition of practical and procedural skills in vocational contexts [1,2]. Research indicates that VR can simulate real work

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scenarios, personalise learning paths, and increase learner engagement, offering transformative opportunities for sustainability-oriented vocational training [1–3]. Similarly, digital learning platforms and interactive pedagogies are increasingly being recognised as drivers of innovation in VET, enabling flexible, competency-based learning that aligns with evolving labour market needs and sustainability goals.

Despite this potential, the integration of advanced digital technologies into VET systems remains fragmented. Many initiatives are limited to pilot projects and lack systemic embedding, long-term strategic alignment, and robust sustainability planning. These challenges are particularly evident in the energy sector, where rapid technological change, regulatory complexity, and regional disparities in skills demand require coordinated and adaptive approaches. As a result, there is a growing need for structured models that combine technological innovation, skills development, and regional engagement in a coherent and sustainable manner.

To address these challenges, the European Commission has promoted the model of Centres of Vocational Excellence (CoVEs) as a strategic mechanism to modernise VET and strengthen its contribution to sustainable development. CoVEs are designed as ecosystem-based hubs that bring together education and training providers, industry, public authorities, and research organisations to jointly design and deliver high-quality, innovation-oriented skills pathways that contribute to regional development, innovation, and inclusion [4]. According to the European Union's Erasmus+ framework, CoVEs support reforms in the VET sector by creating collaborative skills ecosystems that respond to evolving economic and societal needs while advancing inclusivity and sustainability [4,5]. These centres represent a policy-driven effort to embed excellence and innovation in vocational education, including through partnerships that span formal education, enterprises, and innovative actors.

The SECOVE project (Centres of Vocational Excellence in Sustainable Energy) operationalises this model through the establishment of a Centre of Vocational Excellence in Portugal focused on sustainable energy and green technologies. Led by the Polytechnic Institute of Porto, in collaboration with regional energy agencies, innovation consultants, and technology-driven companies, SECOVE adopts an integrated strategic approach that combines technology-enhanced vocational training, applied innovation, and long-term sustainability planning. Its Strategic Development Plan defines a comprehensive portfolio of actions, including VR-based training modules for technical skills development, digital platforms for collaborative learning and skills monitoring, applied innovation projects with enterprises, and the creation of a national observatory to track skills needs in the sustainable energy sector [6].

Against this background, this article adopts a qualitative case study methodology to analyse SECOVE as an illustrative example of how technology-driven vocational education can support sustainability transitions at regional level. The study focuses on three interrelated dimensions: (i) the strategic design of the CoVE and its alignment with sustainability and skills policies; (ii) the role of digital and immersive technologies (particularly, VR and digital platforms) in enhancing vocational training for sustainable energy; and (iii) the governance and ecosystem-based collaboration mechanisms that underpin the CoVE's long-term viability and impact. By providing an in-depth examination of this case, the paper contributes with empirical evidence to the literature on sustainability-oriented VET and offers transferable insights for policymakers, educators, and practitioners involved in the design of technology-enabled CoVEs.

Considering structure, Section 2 presents the methodological approach and case study design; Section 3 describes the SECOVE context, including its strategic objectives, technological components, and ecosystem partnerships; Section 4 discusses the main findings, focusing on the contribution of digital and immersive technologies to skills development and sustainability outcomes; Section 5 summarizes key insights, discussing limitations, and outlining directions for future research.

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2. Materials and Methods

This study adopts a qualitative, descriptive case study methodology to examine the design process of the Strategic Development Plan for SECOVE, the Portuguese Centre of Vocational Excellence (CoVE) in Sustainable Energy. Case study research is particularly suited to capturing the complexity of institutional strategy-making within its real-life context, allowing for an in-depth understanding of governance, operational, financial and ecosystem-related dimensions [7,8].

2.1. Case Study Design and Research Approach

SECOVE is treated as a bounded system, with clearly defined boundaries in terms of organisation (the Portuguese CoVE led by the Polytechnic Institute of Porto), scope (vocational excellence in sustainable energy), partnership structure (core and associated stakeholders), and timeframe (design of the post-project strategic sustainability plan). Defining the case as a bounded system is a core principle of qualitative case study research, ensuring analytical focus and contextual integrity [8,9].

A holistic perspective guided the methodological approach, seeking to understand the CoVE as an integrated system rather than as a set of isolated components, consistent with systems-oriented perspectives on organisational sustainability and educational innovation [10].

To enhance rigour and credibility, methodological triangulation was employed, combining multiple qualitative data sources, including documentary analysis (strategic reports, policy frameworks, grant application forms and project deliverables), semi-structured consultations with core partners and key stakeholders, and direct observation and participatory engagement during strategic planning workshops and project meetings. Triangulation is widely recognised as a key strategy for strengthening validity and robustness in qualitative research [11,12].

The case study is descriptive in nature, aiming to provide a detailed and systematic account of the processes followed to design the strategic development plan, situated within its natural institutional and policy context [7].

Designing the strategic development plan of the Portuguese SECOVE followed several sequential and interrelated steps, including the formulation of its vision and mission, examination of the internal and external environment, definition of strategic objectives, performance of a SWOT analysis, specification of the portfolio of services and products, development of a financial and fundraising plan, and elaboration of an action plan to support implementation.

The methodological approach adopted in this study is consistent with, and contributes to, the emerging body of research on Vocational Education and Training (VET) systems, skills ecosystems, and Centres of Vocational Excellence (CoVEs). Recent VET scholarship increasingly emphasises the need for context-sensitive, qualitative and case-based approaches to understand how vocational institutions respond to complex challenges such as the green transition, skills mismatches and regional development [13,14].

Within this literature, CoVEs are conceptualised not merely as training providers, but as ecosystem orchestrators, operating at the intersection of education, industry, public policy and innovation systems [15,16]. As such, their strategic development cannot be adequately captured through purely quantitative or outcome-driven methods. Instead, descriptive and holistic case study methodologies are widely recognised as appropriate for examining how CoVEs define their missions, mobilise stakeholders, design service portfolios and pursue financial sustainability within specific territorial and institutional contexts [16].

The present study aligns with this perspective by treating SECOVE as a bounded skills ecosystem, embedded in regional, national and European policy frameworks for vocational excellence and sustainable energy. The use of participatory strategic planning, stakeholder mapping and triangulated qualitative data reflects methodological recommendations in VET research that stress co-creation, social partnership and governance analysis as central dimensions of vocational system development [14,17].

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2.2. Vision and Mission Formulation

The first methodological step consisted of collaboratively defining the vision and mission of the Portuguese SECOVE, based on a preliminary understanding of the CoVE's purpose as described in the Erasmus+ CoVE grant application. This process was grounded in a participatory and interpretative approach, involving structured discussions among core partners to articulate a shared long-term ambition and institutional purpose. Participatory visioning is widely acknowledged as a critical element of strategic planning in education and sustainability-oriented organisations [18].

The methodology combined: (1) alignment analysis with European, national and regional policy frameworks related to the green transition and vocational education; (2) reflection on the existing institutional identity, expertise and mandate of the coordinating organisation and Portuguese partners; (3) consensus-building sessions to ensure coherence between ambition, feasibility and ecosystem relevance; and (4) a critical review of the SECOVE purpose statement as defined in the original Erasmus+ grant application.

This step ensured that the vision and mission emerged as stable strategic reference points guiding all subsequent phases of the plan, while remaining anchored in the original partnership mandate.

2.3. Situational Analysis and Stakeholder Mapping

A comprehensive situational and ecosystem analysis was conducted to contextualise the strategic planning process. Methodologically, this involved qualitative analysis of policy documents, regional strategies and sectoral reports, combined with stakeholder consultations. Such contextual analysis is central to strategic planning processes in complex multi-actor environments [18].

Stakeholder mapping followed a structured identification and categorisation process, focusing on external stakeholders (industry, SMEs, public authorities, training providers and sectoral associations) and internal stakeholders (academic units, trainers and management structures). Stakeholders were analysed according to their level of influence, interest and potential contribution to the CoVE's sustainability, drawing on established stakeholder theory and practice [19,20].

This mapping informed strategic prioritisation and partnership design, ensuring that the plan responded to real ecosystem needs rather than abstract assumptions.

2.4. Definition of Objectives

Strategic objectives were defined using a theory-informed and evidence-based approach, translating the vision and situational analysis into a limited set of coherent, medium-term strategic goals. This approach is consistent with best practices in strategic management and public-sector planning [18].

Methodologically, this step involved:

1. identifying strategic domains (skills development, innovation, partnerships and financial sustainability);
2. formulating objectives that were specific, measurable and time-bound;
3. validating objectives through iterative discussions among partners to ensure feasibility and alignment with institutional capacities.

Key performance indicators (KPIs) were subsequently associated with each objective as operational proxies to support monitoring and evaluation.

2.5. SWOT Analysis

A SWOT (Strengths, Weaknesses, Opportunities and Threats) analysis was conducted as a synthesis tool to integrate internal and external insights. The methodology relied on qualitative coding of inputs from document analysis and stakeholder feedback. SWOT analysis is widely used as a structured diagnostic instrument in strategic planning, particularly in education and sustainability-related contexts [21].

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Internal dimensions (strengths and weaknesses) were derived from assessments of organisational capacity, experience and resources, while external dimensions (opportunities and threats) were identified through policy analysis and market scanning. The SWOT analysis supported strategic coherence and risk awareness.

2.6. Specification of the Portfolio of Services and Products

The design of the services and products portfolio followed a needs-driven and modular methodology. Rather than listing outputs, this step focused on defining categories of intervention aligned with the CoVE's strategic objectives and partners' interests.

Methodologically, this involved mapping existing competencies and infrastructures, identifying gaps between market needs and current provision, and structuring services into coherent clusters (education, innovation support, networking and community engagement). Modular and adaptive portfolio design is increasingly recognised as a key enabler of sustainability in education and training ecosystems [16].

This approach ensured that the portfolio is strategically aligned, scalable and adaptable over time.

2.7. Financial Planning and Budget Estimation

The financial plan and budget estimation were developed using a scenario-based and incremental costing methodology. Operational cost categories were identified first, followed by estimations based on realistic staffing, infrastructure and activity levels, ensuring that strategic planning was grounded in economic realism rather than aspirational assumptions [18].

The methodology prioritised: transparency in cost structures; medium-term financial projections (3-5 years); and alignment between strategic ambitions and financial feasibility.

Fundraising Strategy

The fundraising strategy was designed as a diversification exercise, aiming to reduce dependency on single funding sources. Methodologically, this involved mapping potential funding programmes at European, national and regional levels, identifying revenue-generating services compatible with the SECOVE mission, and defining partnership-based funding mechanisms. Diversified funding models are widely recommended for enhancing the long-term sustainability of education and innovation initiatives [16].

The strategy was developed iteratively, linking funding sources to specific strategic objectives and activities, thereby strengthening coherence between strategy and financing.

2.8. Action Plan Development

The final methodological step consisted of translating the strategic framework into an action plan. This followed a logical sequencing approach, defining actions, responsibilities, timelines and resource requirements. Action planning is a critical bridge between strategy formulation and implementation, particularly in complex multi-stakeholder initiatives [18].

The action plan was constructed as a living instrument, designed to support adaptive management. It operationalised strategy while allowing flexibility for contextual changes, reinforcing the long-term sustainability of the Portuguese SECOVE.

2.9. Methodological Rigor and Limitations

The use of a qualitative, descriptive case study enabled a rich and contextualised understanding of the strategic design process. Triangulation across data sources enhanced validity, while the bounded nature of the case ensured analytical focus [7,12]. As with most case studies, findings are context-specific; however, the methodological approach offers transferable insights for other Centres of Vocational Excellence seeking sustainable strategic positioning.

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By documenting the processes through which the SECOVE strategic development plan was designed, rather than focusing solely on outputs or performance indicators, this case study contributes to a growing strand of VET and CoVE research concerned with institutional capacity-building, strategic governance and long-term sustainability. In this sense, the methodology not only aligns with existing VET scholarship but also offers transferable methodological insights for other Centres of Vocational Excellence operating in the context of the green and digital transitions.

3. Results

This section presents the results of the qualitative case study analysis of the Portuguese SECOVE Centre of Vocational Excellence, drawing on documentary analysis of the Strategic Development Plan, internal reports, and stakeholder mapping outputs. The results are structured around four complementary analytical dimensions: (i) the outcomes of the SWOT analysis, which provide insight into the internal and external factors shaping the CoVE's strategic positioning; (ii) the stakeholder analysis, which examines the composition and relevance of the collaborative ecosystem supporting the CoVE; (iii) the definition of strategic objectives and associated key performance indicators (KPIs) over a five-year horizon; and (iv) the portfolio of educational, innovation, and community-oriented services and products. Together, these dimensions offer a comprehensive view of how the SECOVE CoVE operationalises technology-enhanced vocational education to support sustainability and the energy transition at regional level [22].

3.1. SWOT Analysis Outcomes

The SWOT analysis identifies a robust set of internal strengths that support the strategic positioning and operational capacity of the SECOVE Centre of Vocational Excellence. A key strength lies in the extensive experience of GILT in coordinating and participating in European projects focused on education, innovation, and technology-enhanced learning. This experience provides institutional credibility, administrative capacity, and access to transnational networks, which are widely recognised as critical success factors for Centres of Vocational Excellence and skills ecosystems (European Commission, 2020; Cedefop, 2021). In addition, the CoVE benefits from long-standing partnerships with education and training providers, technology centres, and companies operating in the energy sector, enabling strong alignment between training provision, technological innovation, and labour market needs.

Another significant strength is the CoVE's capacity to mobilise learners and trainers in authentic work-based and challenge-driven learning environments. This is reflected in the implementation of dual training schemes, internships, and challenge-based learning approaches that integrate real industrial problems into training pathways. Such approaches have been shown to enhance employability, facilitate skills transfer, and improve the relevance of vocational education in rapidly evolving sectors such as sustainable energy (OECD, 2020; Cedefop, 2022).

Despite these strengths, the analysis also reveals a set of internal weaknesses primarily related to structural and organisational constraints. One of the most salient challenges is the CoVE's continued dependence on European funding instruments to support development, innovation, and experimentation activities. While project-based funding has enabled rapid implementation and innovation, it also creates vulnerabilities in terms of long-term financial stability, a challenge commonly reported in European VET innovation initiatives (Cedefop, 2020). Additionally, the need to further consolidate the CoVE's institutional identity as an autonomous and sustainable structure emerged as a key weakness, particularly in relation to governance, branding, and market positioning. Finally, limited short-term capacity to respond to large-scale demand for certified vocational training was identified, highlighting the need for phased growth and strategic prioritisation.

From an external perspective, the SWOT analysis highlights substantial opportunities arising from strong alignment with European, national, and regional policy frameworks. These include access to funding through programmes such as Erasmus+, ESF+, Horizon Europe, and LIFE-CET; coherence with national and regional smart specialisation strategies (RIS3); and alignment with

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energy transition and decarbonisation agendas. Moreover, the increasing demand for specialised technical skills in renewable energy, energy efficiency, and the circular economy represents a significant opportunity for the CoVE to position itself as a regional skills hub. These findings are consistent with European and international analyses that identify green skills development as a cornerstone of the twin green and digital transitions (European Commission, 2021; OECD, 2023).

Conversely, the main threats identified include intensifying competition from private training providers characterised by greater commercial flexibility and faster technological adoption, political uncertainty and potential shifts in public funding mechanisms, and resistance to pedagogical and organisational change among actors embedded in traditional vocational education and training systems. Such threats reflect broader systemic barriers to VET reform identified in the literature, particularly in contexts undergoing rapid technological and sustainability-driven transformation (Cedefop, 2021).

3.2. Stakeholder Analysis Results

The stakeholder analysis provides further insight into the ecosystem-based nature of the SECOVE CoVE. The mapping exercise identified a diverse group of external actors with high strategic relevance and collaboration potential, including companies operating in the energy, construction, technology, and industrial sectors; business and industrial associations; regional and local public authorities; and other vocational education and training providers and higher education institutions.

The results indicate that these stakeholders are expected to play an active and multifaceted role in the CoVE's activities, including participation in the co-design and delivery of training programmes, involvement in applied innovation and pilot projects, and contribution to knowledge transfer and skills anticipation mechanisms. This multi-actor engagement is consistent with the skills ecosystem approach underpinning the CoVE model, which emphasises shared responsibility, co-creation, and alignment between education, innovation, and regional development objectives (European Commission, 2020; OECD, 2021).

Importantly, the analysis highlights that the long-term success and sustainability of the CoVE are strongly dependent on the consolidation, formalisation, and effective governance of these collaborative networks. Stable partnership frameworks, clear role definitions, and mechanisms for continuous stakeholder engagement are essential to ensure that collaboration moves beyond ad hoc participation towards sustained strategic alignment. This finding reinforces existing evidence that governance capacity and stakeholder coordination are decisive factors in the effectiveness and resilience of Centres of Vocational Excellence and regional innovation ecosystems (Cedefop, 2022).

3.3. Strategic Objectives and KPIs (5-Year Horizon)

Based on the SWOT and stakeholder analysis, the CoVE defined four strategic objectives to guide its development over a five-year horizon. These objectives translate strategic priorities into operational directions and measurable outcomes.

The first objective aims to enhance technical and green competencies that support energy and digital transitions, while contributing to sustainable regional economic development. Training programs target learners in initial education, professionals engaged in reskilling and upskilling processes, and technicians and middle-management professionals in the energy, environmental, and digital sectors. In this context, the CoVE acts as a regional catalyst for knowledge, skills development, and innovation, responding to labor market needs and supporting the availability of qualified technical talent required for the energy transition in Northern Portugal.

The second objective seeks to position the CoVE as a national and European reference for applied innovation in sustainable energy and technology-driven solutions. The CoVE promotes co-creation and implementation of innovations in collaboration with SMEs, public entities, and startups, functioning as a hub for technological experimentation, testing, and prototyping of products and services. Consolidation as a centre for applied innovation is expected to contribute to regional

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business modernisation, enhance sectoral competitiveness, and accelerate the adoption of sustainable technologies.

The third objective focuses on strengthening and expanding collaboration networks with institutional, business, educational, and community partners at regional, national, and European levels. Such partnerships are essential for sharing resources, developing joint initiatives, integrating good practices, and ensuring the long-term sustainability and relevance of CoVE activities.

Finally, the fourth objective addresses the financial sustainability of the CoVE by promoting progressive autonomy through a diversified funding strategy. This strategy combines internally generated revenue with national and European funding sources. Key mechanisms include paid training programs, participation in R&D&I projects, and strategic partnerships with measurable financial impact. This diversified model is designed to ensure operational continuity beyond the initial European funding period and to support future regional expansion (Cedefop, 2020).

3.4. Portfolio of Services and Products

This subsection presents the portfolio of services and products developed within the SECOVE Centre of Vocational Excellence, reflecting the operationalisation of its strategic objectives into concrete educational, innovation, and community-oriented actions. The portfolio is designed to address identified skills gaps, support applied innovation in sustainable energy, and foster ecosystem-based collaboration at regional and national levels. It integrates formal education, continuous professional development, innovation support, and networking activities, with a strong emphasis on digitalisation, immersive technologies, and sustainability principles. Together, these services and products constitute the core mechanisms through which the CoVE delivers impact in terms of skills development, technological innovation, and regional sustainability.

3.4.1. Educational Offerings

The educational portfolio comprises higher education programmes at EQF levels 6–8 and vocational education and training programmes at EQF levels 4–5 in areas such as renewable energy, energy management, energy efficiency, and maintenance of hybrid systems. In addition to initial education pathways, the portfolio includes reskilling and upskilling programmes for professionals, dual training schemes, challenge-based learning approaches, and certification of green and digital competencies. These offerings are delivered through in-person, blended, and online formats and are increasingly supported by digital platforms and immersive technologies, including virtual reality, which enhance experiential learning, safety, and skills transfer in technical training contexts (OECD, 2020; Cedefop, 2022).

3.4.2. Innovation Services

Innovation services focus on supporting SME digitalisation and technological innovation through applied research projects addressing energy transition challenges, access to laboratory infrastructures and digital platforms, and assistance in the adoption of emerging technologies and sustainable practices. By facilitating collaboration between education providers, companies, and public entities, these services strengthen knowledge transfer and reinforce the CoVE's role as an intermediary within the regional innovation ecosystem, in line with smart specialisation and sustainability-oriented innovation strategies (European Commission, 2021).

3.4.3. Networking and Community Services

Networking and community-oriented services include the organisation of hackathons, seminars, technical events, and thematic fairs, as well as the creation and activation of the SECOVE community, involving students, companies, trainers, and policymakers. The management of a collaborative digital platform further supports interaction, knowledge sharing, and dissemination of good practices. Across all activities, the CoVE integrates principles of inclusion, gender equality, and just

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transition, reflecting broader sustainability and social cohesion objectives embedded in European skills and energy policies (OECD, 2021).

4. Discussion

The establishment of SECOVE reflects broader structural transformations occurring within vocational education and training (VET) systems as a response to the green and digital transitions. The results of this study indicate that Centres of Vocational Excellence can operate as strategic intermediaries between education, innovation, and regional development, particularly in territories experiencing skills shortages and economic restructuring, such as Northern Portugal.

The findings derived from the SWOT and stakeholder analyses demonstrate that the effectiveness of the CoVE model is strongly dependent on its capacity to mobilise existing institutional expertise, consolidate multi-actor partnerships, and adapt to evolving labour market needs. In the case of SECOVE, a strong alignment was identified between the CoVE's strategic objectives and European and national policy frameworks, including the European Green Deal, the EU Skills Agenda, and RIS3 strategies. This alignment supports the interpretation of CoVEs not merely as advanced training providers, but as policy-embedded instruments that contribute to the implementation of sustainability-oriented development strategies. These results are consistent with recent academic literature that conceptualises CoVEs as governance mechanisms within regional innovation ecosystems, rather than isolated educational institutions.

A central result of the SECOVE case concerns its integrated approach to skills development. The CoVE combines formal vocational education and training, higher education pathways, and applied innovation activities within a single strategic framework. The strong emphasis on experiential and work-based learning, supported by immersive digital technologies such as VR, reflects contemporary pedagogical approaches that stress the value of simulation-based and challenge-driven learning in technical education. According to the findings, these approaches enhance learner engagement, facilitate the acquisition of complex technical competences, and support smoother transitions between education and employment, particularly in technology-intensive sectors such as sustainable energy.

The stakeholder analysis further highlights the relevance of collaborative governance models in the functioning of the CoVE. The active involvement of SMEs, industry associations, public authorities, and education and training institutions reflects a quadruple-helix logic, in which skills development, knowledge creation, and innovation are co-produced across institutional boundaries. This configuration increases the responsiveness of training provision to real-world challenges, strengthens knowledge transfer mechanisms, and enhances regional innovation capacity. At the same time, the results reveal persistent structural challenges, including resistance to change within traditional training systems and competitive pressures from more agile private training providers, which may constrain the pace and depth of institutional transformation.

From a social sustainability perspective, the results underline the significance of SECOVE's explicit focus on inclusion and gender equality, embedded as cross-cutting principles within its activities. This orientation aligns with EU sustainability objectives and responds to growing evidence that energy and digital transitions risk reinforcing existing inequalities if skills policies are not deliberately inclusive. The SECOVE case illustrates how CoVEs can integrate social objectives into technically oriented training frameworks, thereby contributing to a more equitable transition to a green economy.

Despite these positive outcomes, the analysis also identifies limitations inherent to emerging CoVE structures, particularly regarding institutional consolidation and long-term financial and organisational autonomy. While such constraints are common in innovation-driven educational initiatives, the results highlight the importance of adaptive governance arrangements, continuous stakeholder engagement, and sustained policy coherence to ensure long-term impact and scalability.

Overall, the results support the conclusion that Centres of Vocational Excellence, when strategically aligned with regional needs and policy agendas, can act as effective catalysts for

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sustainable development. The SECOVE case provides empirical evidence of how vocational education, applied innovation, and collaborative governance can be integrated into a coherent model capable of addressing skills gaps, supporting regional energy transitions, and contributing to broader sustainability objectives. These findings also suggest avenues for future research, particularly regarding the transferability of the CoVE model to other regional contexts and its long-term effects on employment, innovation performance, and social inclusion.

5. Conclusions

This study examined the Portuguese SECOVE Centre of Vocational Excellence as a case study of technology-enhanced vocational education and training (VET) supporting sustainability and the energy transition at regional level. The analysis of strategic planning documents and institutional data provides an integrated view of the governance model, strategic orientation, technological components, and operational mechanisms through which the CoVE addresses skills development, innovation, and long-term sustainability in the sustainable energy sector.

The results show that the SECOVE CoVE adopts a holistic and ecosystem-based approach to vocational excellence that integrates education and training, applied innovation, and multi-stakeholder collaboration. The SWOT and stakeholder analyses identify a strong institutional foundation based on extensive experience in European projects, consolidated partnerships, and the capacity to implement authentic work-based and challenge-driven learning models. These characteristics position the CoVE as a relevant regional actor aligned with labour market needs and sustainability priorities. Structural challenges are also identified, particularly dependence on project-based funding and the need to consolidate institutional identity. These elements require strategic management to support long-term resilience and scalability.

A central contribution of the SECOVE model is the systematic integration of digital and immersive technologies in vocational education and training. The use of virtual reality, digital learning platforms, and technology-supported training pathways enhances experiential learning, safety, and skills transfer in technically complex domains such as renewable energy and energy efficiency. This technological integration strengthens the relevance and adaptability of VET provision and supports the development of green and digital competencies required for the energy transition. The findings reinforce existing evidence on the role of digital technologies in sustainability-oriented education while illustrating their structured implementation within a Centre of Vocational Excellence.

The definition of strategic objectives and key performance indicators over a five-year horizon provides a structured framework for monitoring progress and ensuring alignment with regional, national, and European policy agendas. The focus on skills development, applied innovation, partnership expansion, and financial sustainability reflects a balanced strategy addressing operational needs and long-term impact. Diversification of funding sources and the development of revenue-generating services emerge as key conditions for continuity beyond the initial European funding period.

The study offers practical insights for policymakers, education providers, and practitioners involved in the design and implementation of Centres of Vocational Excellence and related initiatives. The SECOVE case illustrates the operationalisation of technology-enhanced VET through structured governance, ecosystem-based collaboration, and strategic alignment with sustainability objectives. The integration of innovation services and community-oriented activities alongside formal education provision contributes to regional impact and stakeholder engagement.

The study presents limitations associated with its single case study design and the reliance on documentary and strategic planning data. These factors limit the assessment of outcomes related to learner performance, employability, and long-term sustainability effects. Further research may adopt comparative case study designs, include longitudinal data, and incorporate perspectives from learners, trainers, and industry partners.

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Future research may also focus on empirical evaluation of immersive technologies in vocational training for sustainable energy and on the development of metrics to assess social, economic, and environmental impacts of Centres of Vocational Excellence. Such work would strengthen the evidence base supporting technology-driven VET as an instrument for sustainability transitions.

The SECOVE Centre of Vocational Excellence represents an example of integrated, technology-enhanced vocational education supporting green skills development, applied innovation, and sustainable regional development. The alignment of education, technology, and collaboration within a coherent strategic framework provides transferable insights for the design of future Centres of Vocational Excellence and for broader efforts to align skills systems with sustainability and energy transition goals.

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Abbreviations

The following abbreviations are used in this manuscript:

CoVE	Portuguese Center of Vocational Excellence
SECoVE	Portuguese Center of Vocational Excellence in Sustainable Energy
VR/AR	Virtual Reality/Augmented Reality
VET	Vocational Education and Training

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