Outlining a case study for embedding sustainability competences

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Abstract. The imperative to embed sustainability competences within engineering education has gained unprecedented urgency in the face of escalating global environmental, social, and economic challenges. Higher Education Institutions (HEIs) across Europe are increasingly tasked with equipping future engineers not only with technical proficiency but also with the knowledge, skills, and attitudes necessary to address complex sustainability issues. The integration of sustainability into engineering education is increasingly recognized as a critical imperative in the face of global environmental and societal challenges. The "Engineering Education for a Sustainable Future" (EESF) project, co-funded by the Erasmus+ Programme of the European Union, represents a collaborative effort among seven European institutions to embed sustainability competences into undergraduate engineering curricula. This article presents a detailed account of the methodology employed in the EESF research study, which aimed to identify current practices, assess gaps, and propose strategies for aligning engineering education with sustainability goals. Through a qualitative research design involving 53 semi-structured interviews with stakeholders across academia and industry, the study offers a comprehensive understanding of the challenges and opportunities in embedding sustainability competences in higher education institutions (HEIs). This study will also compare the project with other projects that have already been carried out.

Keywords: Sustainability, Engineering, Education.

1 INTRODUCTION

The integration of sustainability into higher education curricula has become a global imperative in response to the escalating environmental, social, and economic challenges confronting contemporary society. As the world grapples with climate change, biodiversity loss, resource depletion, and widening social inequalities, the role of education, particularly higher education institutions (HEIs), in fostering sustainable development has gained renewed urgency. The United Nations' 2030 Agenda for Sustainable Development explicitly recognizes education as a critical enabler of all 17 Sustainable Development Goals (SDGs) [1], with Target 4.7 calling for the acquisition of knowledge and skills necessary to promote sustainable development through education at all levels [2]. In this context, HEIs are increasingly expected to act as transformative agents, not only by generating knowledge through research but also by embedding sustainability competences into their teaching and learning practices. These competences encompass a range of cognitive, affective, and behavioral attributes, including systems thinking, anticipatory thinking, normative reasoning, strategic action, and interpersonal collaboration [2]. The goal is to prepare graduates who are not only technically proficient in their disciplines but also able to of addressing complex sustainability challenges in interdisciplinary and socially responsible ways.

Historically, engineering education emerged in the service of industrialization and empire-building. As Lucena and Schneider (2014) illustrate, the earliest engineering schools were established to support state consolidation and colonial expansion, with engineers playing a central role in constructing infrastructure that enabled resource extraction and territorial control [3]. This legacy of engineering as a tool for economic and political power has shaped the profession's identity and educational foundations. However, the environmental and social consequences of unchecked industrial development have led to a growing recognition of the need for a new kind of engineering who is equipped to address the complex, interconnected challenges of sustainable development. The concept of *sustainable development* gained global prominence with the 1987 Brundtland Report and was institutionalized through the United Nations Sustainable Development Goals (SDGs) in 2015 [1]. These frameworks have underscored the need for systemic change in education, particularly in disciplines like engineering that directly influence infrastructure, energy, and technology systems. As Desha et al. (2009) argue, engineering education must undergo rapid curriculum renewal to prepare graduates capable of designing sustainable solutions in a world facing unprecedented environmental pressures [4]

Despite this growing consensus, the operationalization of sustainability within higher education remains uneven and fragmented. A recent review by Lee (2025) highlights that while many universities have aligned their mission statements and strategic plans with the SDGs, the actual integration of sustainability into curricula is often hindered by structural fragmentation, disciplinary silos, and outdated pedagogical models [2]. Education for Sustainable Development (ESD), which promotes participatory, transformative, and systems-oriented learning, has emerged as a key pedagogical framework. However, its implementation across disciplines—particularly in technical and professional fields such as engineering, business, and health sciences—remains

inconsistent. One of the central challenges in embedding sustainability competences lies in the traditional structure of university curricula, which are often rigid, discipline-specific, and slow to adapt to emerging societal needs. As Fernández-Villarán et al. (2024) argue, curriculum reform must go beyond the mere addition of sustainability-related modules or electives. Instead, it requires a holistic rethinking of learning outcomes, pedagogical strategies, and assessment methods to ensure that sustainability is integrated across all levels and areas of study [5]. This includes fostering critical and strategic thinking, ethical reflection, and the ability to navigate uncertainty and complexity—skills that are essential for future professionals in all sectors.

Moreover, embedding sustainability competences necessitates a shift in institutional culture and governance. Mulder et al. (2012) emphasize the importance of faculty engagement and institutional support in driving curricular change. Their case studies from European technical universities demonstrate that meaningful integration of sustainability often begins with individual educators who champion the cause, but long-term success depends on systemic support, including professional development, interdisciplinary collaboration, and recognition of sustainability teaching in academic evaluations [6]. Digital transformation also plays a dual role in this process. On one hand, digital tools such as e-learning platforms and smart campus technologies offer new opportunities for experiential and collaborative learning. On the other hand, digital inequities and the lack of pedagogical training in digital environments can exacerbate existing barriers to sustainability education [2]. Therefore, digital strategies must be thoughtfully designed to enhance, rather than hinder, the integration of sustainability competences.

Another critical dimension is the alignment between academic curricula and labor market expectations. Employers increasingly seek graduates who possess not only domain-specific knowledge but also transversal skills such as communication, teamwork, adaptability, and ethical reasoning. These attributes are closely aligned with sustainability competences, yet they are often underemphasized in traditional academic programs. There is a pressing need for robust assessment tools that can evaluate students' sustainability competences in authentic, practice-based contexts [7]. The literature also underscores the value of interdisciplinary and transdisciplinary approaches in sustainability education. The European GreenComp framework advocates for the integration of sustainability competences across disciplines, encouraging students to think and act with empathy, responsibility, and care for the planet [8]. This requires breaking down academic silos and fostering collaboration among departments, faculties, and external stakeholders, including industry, government, and civil society.

In practice, successful models of sustainability integration often involve project-based learning, community engagement, and real-world problem-solving. For instance, Beagon et al. (2022) describe how engineering programs can incorporate sustainability through design challenges, internships, and interdisciplinary capstone projects that address local and global sustainability issues [9]. These experiential learning opportunities not only enhance students' technical and soft skills but also cultivate a sense of agency and civic responsibility. However, the path toward comprehensive sustainability integration is fraught with challenges. Blanco-Portela et al. (2017) identify several barriers, including limited financial resources, lack of institutional leadership,

resistance to change, and insufficient faculty training [10]. Overcoming these obstacles requires a coordinated effort at multiple levels—policy, institutional, departmental, and individual. It also demands a redefinition of academic excellence to include contributions to sustainability, both in teaching and research.

In conclusion, embedding sustainability competences in higher education curricula is a complex but essential endeavor. It calls for a paradigm shift in how knowledge is produced, transmitted, and applied. HEIs must move beyond symbolic commitments to sustainability and embrace transformative practices that prepare students to navigate and shape a rapidly changing world. This involves reimagining curricula, empowering educators, leveraging digital tools, and fostering partnerships that bridge academia and society. As the global community strives to achieve the SDGs by 2030, the role of higher education in cultivating sustainability-literate graduates has never been more critical.

2 Embedding Sustainability Competences in Engineering Education: Methodological Insights from the EESF Project and a comparative approach

In the face of escalating global challenges — ranging from climate change and biodiversity loss to resource depletion and social inequality — there is a growing consensus that higher education must play a transformative role in fostering sustainable development. Engineering, as a discipline that shapes the physical and technological infrastructure of society, is uniquely positioned to contribute to this transformation. However, traditional engineering education has often prioritized technical proficiency over broader social and environmental considerations. This gap has prompted calls for a paradigm shift in how engineers are educated, emphasizing the integration of sustainability competences into curricula.

The EESF project is a collaborative endeavor co-funded by the Erasmus+ Programme of the European Union. It brings together a diverse consortium of seven partners: Atlantic Technological University (ATU), Universidad Politécnica de Madrid (UPM), Politécnico do Porto (P. Porto), Institut Mines-Télécom Business School (IMTBS), the European E-Learning Institute, Momentum, and Wind Energy Ireland (WEI). These institutions represent a cross-section of expertise in engineering, education, sustainability, and digital learning. The overarching goal of the EESF project is to raise the standard and relevance of engineering education at European Qualifications Framework (EQF) levels 5 and 6 by embedding sustainability competences into curricula, pedagogy, and institutional practices. By doing so, the project seeks to prepare a new generation of engineers who are not only technically skilled but also capable of addressing complex sustainability challenges through interdisciplinary collaboration, ethical reasoning, and systems thinking. Sustainability competences refer to the integrated sets of knowledge, skills, values, and attitudes that enable individuals to contribute effectively to sustainable development. These competences are inherently interdisciplinary and context-dependent, encompassing cognitive, affective, and behavioral dimensions. According to the European Commission's GreenComp framework, key

sustainability competences include systems thinking, critical thinking, futures thinking, collaboration, and self-awareness. In the context of engineering education, sustainability competences extend beyond technical expertise to include the ability to design solutions that are environmentally sound, socially equitable, and economically viable. This requires a rethinking of traditional curricula to incorporate topics such as life cycle assessment, circular economy, renewable energy systems, and sustainable design principles. Moreover, it necessitates pedagogical innovations that foster experiential learning, stakeholder engagement, and reflective practice. The EESF project builds upon a growing body of research and institutional initiatives aimed at integrating sustainability into higher education. In addition, the EESF project aligns with the work of engineering accreditation bodies such as Engineers Ireland and the UK Engineering Council, which have increasingly emphasized sustainability in their professional standards. Reports from these organizations indicate a growing recognition among engineering professionals of their responsibility to contribute to a sustainable future. However, they also point to persistent gaps in how sustainability is taught and assessed in engineering programs.

Against this backdrop, the EESF research study was designed to investigate the current state of sustainability education in European engineering programs, identify best practices, and propose strategies for improvement. The study was guided by the following research questions:

1. What sustainability competences are currently being taught in engineering programs at European HEIs?
2. What pedagogical and institutional practices are used to teach these competences?
3. What are the strengths and limitations of these practices?
4. To what extent do current educational practices align with the sustainability skills demanded by industry?

By addressing these questions, the study aims to generate actionable insights that can inform curriculum development, faculty training, and policy-making in engineering education.

The significance of the EESF project lies in its potential to catalyze systemic change in engineering education. By adopting a multi-stakeholder, cross-national approach, the project not only maps the current landscape of sustainability education but also fosters a community of practice among educators, researchers, and industry partners. Its findings contribute to the broader discourse on education for sustainable development (ESD) and offer a model for other disciplines seeking to integrate sustainability into their curricula. Moreover, the project's emphasis on qualitative, interview-based research provides rich, context-sensitive data that complement existing quantitative studies. This methodological choice allows for a deeper understanding of institutional cultures, pedagogical philosophies, and practical constraints that shape sustainability education in engineering. In this context, the EESF project emerges not only as a response to policy imperatives but also as a proactive initiative to bridge the gap between academic instruction and the evolving demands of the engineering profession. The project recognizes that while many higher education institutions have made strides in integrating sustainability into their curricula, these efforts are often fragmented,

inconsistent, and lacking in strategic coherence. Some institutions have adopted comprehensive frameworks that embed sustainability across all levels of teaching and research, while others rely on isolated modules or the initiative of individual faculty members. This disparity underscores the need for a more systematic and evidence-based approach to curriculum reform. The EESF project seeks to address this need by conducting a thorough investigation into how sustainability competences are currently being taught in engineering programs across Europe. By engaging with a diverse range of stakeholders — including faculty, institutional leaders, vocational education providers, accreditation bodies, and industry representatives — the project aims to capture a holistic picture of the current landscape. This approach ensures that the voices of those directly involved in both the delivery and application of engineering education are heard and considered in the development of future strategies. Central to the project's philosophy is the belief that sustainability education must go beyond the transmission of knowledge. It must cultivate a mindset oriented toward long-term thinking, ethical responsibility, and collaborative problem-solving. This requires not only curricular innovation but also a transformation in pedagogical practices, institutional culture, and stakeholder engagement. The EESF project therefore positions itself as both a research initiative and a catalyst for change, aiming to influence policy, practice, and perception within the engineering education community. The research component of the project is designed to generate actionable insights that can inform the development of teaching resources, training programs, and institutional policies. By identifying best practices and common barriers, the study provides a foundation for the creation of tools and frameworks that can support the integration of sustainability competences in a scalable and adaptable manner. Moreover, by aligning its findings with established frameworks such as the European GreenComp and the SDGs, the project ensures that its recommendations are grounded in internationally recognized standards.

What distinguishes the EESF project is its commitment to contextual sensitivity and stakeholder inclusivity. Rather than imposing a one-size-fits-all model, the project acknowledges the diversity of institutional contexts, disciplinary traditions, and national education systems. It seeks to identify principles and practices that are both effective and adaptable, allowing institutions to tailor their approaches to their specific needs and capacities. This flexibility is particularly important in a field as dynamic and interdisciplinary as sustainability, where solutions must be responsive to local realities while contributing to global goals. The project also emphasizes the importance of aligning educational outcomes with labor market expectations. As industries increasingly adopt sustainable business models and seek professionals with sustainability expertise, there is a growing demand for graduates who can navigate the technical, regulatory, and ethical dimensions of sustainability. The EESF study explores this alignment by engaging with industry stakeholders to understand their expectations and identify gaps in current educational practices. This dialogue between academia and industry is essential for ensuring that engineering graduates are not only employable but also capable of driving innovation and sustainability in their professional roles.

As engineering professionals are increasingly expected to contribute to sustainable development, higher education institutions (HEIs) are under pressure to reform curricula, pedagogical strategies, and institutional frameworks to prepare graduates with the

necessary knowledge, skills, and attitudes. However, the methodologies employed to achieve this integration vary significantly across contexts, reflecting diverse educational philosophies, institutional capacities, and disciplinary traditions.

This comparative analysis aims to examine and contrast five prominent methodological approaches to embedding sustainability competences in engineering education. Central to this comparison is the methodology adopted by the Engineering Education for a Sustainable Future (EESF) project, a European initiative that employed a qualitative, stakeholder-driven approach to explore how sustainability is currently taught and perceived across HEIs and industry. The EESF methodology is compared with other influential studies as shown below in table 1.

Table 1: Comparison between methodologies adopted in different projects.

Study Name	Methodology Type	Data Collection Method	Strenghts	Limitations
EESF Project	Qualitative	Semi-structured interviews	Deep understanding of institutional cultures and stakeholder perceptions	Context-dependent findings, limited generalizability
Miñano Rubio et al. (2019) [11]	Exploratory	Curriculum analysis and document review	Macro-level view of curriculum structure	Fragmented integration, lacks strategic coherence
EDINSOST Project [12]	Structured	Surveys and competency mapping	Replicable framework, guides faculty development	May overlook contextual nuances
Segalàs et al. (2009) [13]	Tool-based	Development of assessment rubrics	Measurable learning outcomes, alignment with SDG targets	Focuses on tools, may miss broader pedagogical insights
Tejedor et al. (2019) [14]	Bibliometric	Systematic literature review	Meta-perspective on field trends and gaps	May lack depth in specific institutional practices
Competences Map on Sustainability in Higher Education [15]	Quantitative	Competency mapping, surveys	Structured, replicable framework; facilitates development of assessment tools	May overlook contextual nuances and stakeholder perspectives
Implementing the SDGs at University Level [16]	Mixed-methods	Surveys, interviews, case studies	Combines quantitative and qualitative insights; comprehensive analysis.	Resource-intensive; may face challenges in data integration.
Introducing Sustainable Development in Engineering Education [17]	Qualitative	Case studies, interviews	In-depth exploration of specific contexts; rich qualitative data	Limited generalizability; context-specific findings.

3 CONCLUSIONS

By analyzing methodologies side by side, this study seeks to highlight their respective strengths, limitations, and contributions to the field. The goal is not only to understand how different research designs shape our understanding of sustainability integration but also to identify best practices and potential synergies that can inform future educational reforms. This comparative perspective is essential for advancing a more coherent, effective, and context-sensitive approach to sustainability education in engineering, one that aligns academic training with the complex demands of the 21st-century workforce and society. In sum, the EESF project represents a comprehensive and forward-looking effort to embed sustainability competences in engineering education. It combines rigorous research with practical application, stakeholder engagement with policy alignment, and institutional analysis with pedagogical innovation. By doing so, it contributes to the broader movement toward education for sustainable development and offers a model for how interdisciplinary, collaborative, and context-sensitive approaches can drive meaningful change in higher education.

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