Engineering Education
for a Sustainable Future

Research Report

Embedding Sustainability Competences

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CONTENTS

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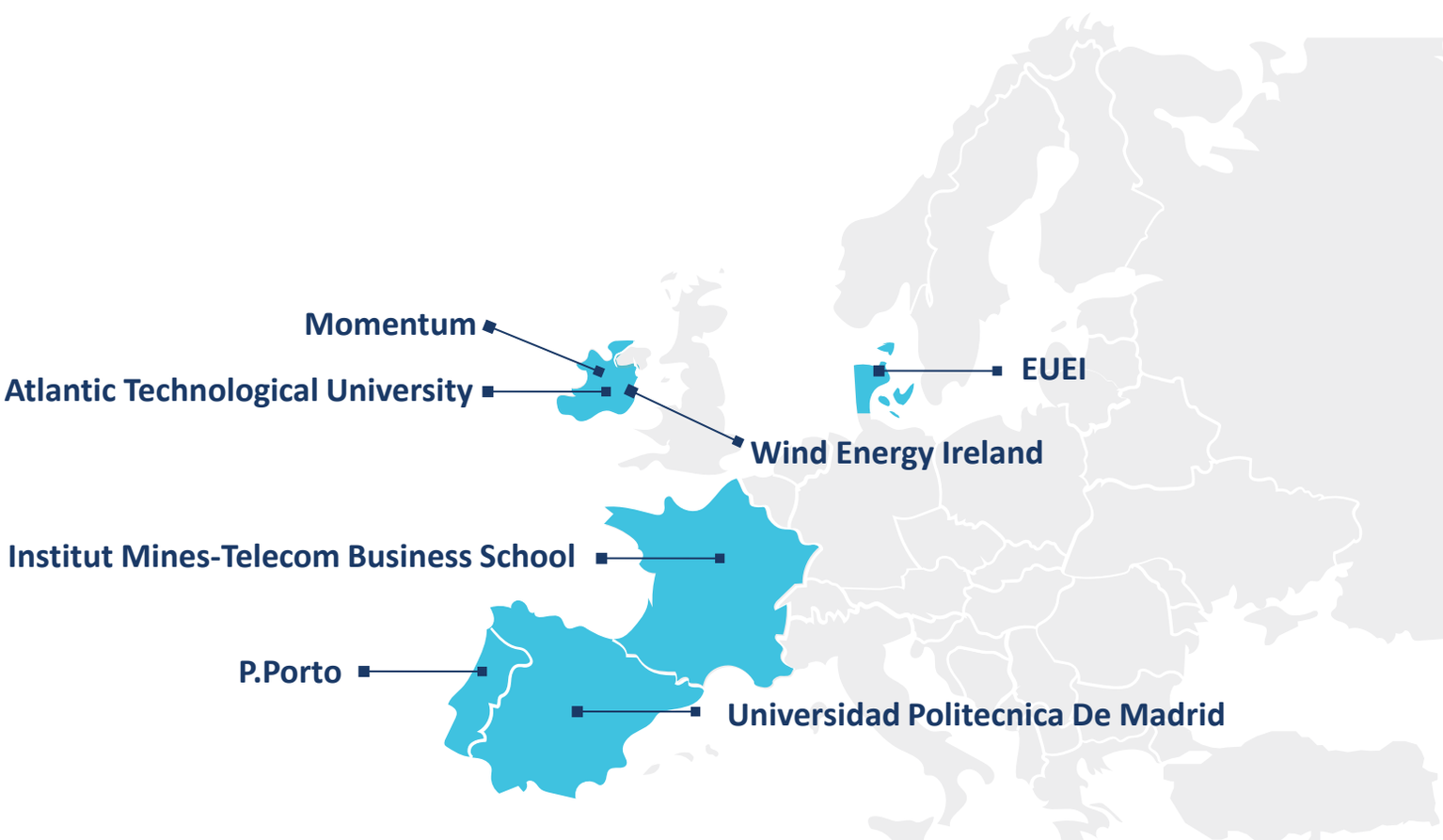
Abbreviations

ATU	Atlantic Technological University
CPD	Continuing Professional Development
EESF	Engineering Education for a Sustainable Future
EQF	European Qualifications Framework
EU	European Union
EULiST	European Universities Linking Society and Technology
GRI	Global Reporting Initiative
HEI	Higher Education Institute
IMTBS	Institut Mines-Télécom Business School
LCA	Life Cycle Assessment
NGO	Non-Governmental Organisation
P. Porto	Politécnico do Porto
SDG	Sustainable Development Goal
UN	United Nations
UPM	Universidad Politécnica de Madrid
VET	Vocational Education and Training
WCED	World Commission on Environment and Development
WEI	Wind Energy Ireland

Our Partners

The EESF Project brings together a dynamic consortium of European institutions dedicated to advancing sustainability in engineering education. Partners include Atlantic Technological University, Institut Mines-Télécom Business School, Universidad Politécnica de Madrid, Instituto Superior de Engenharia do Porto. European E-Learning Institute, Momentum and Wind Energy Ireland,

Together, these institutions leverage their expertise in education, innovation, and sustainability to develop impactful resources and training that will shape the next generation of engineers.



Oilscoil Teicneolaíochta an Atlantaigh
Atlantic Technological University
European E-Learning Institute
Institut Mines-Télécom Business School
momentum [educate + innovate]
POLITÉCNICA
WIND ENERGY IRELAND
isep Instituto Superior de Engenharia do Porto

Abstract

Abstract

Rapid population growth has intensified social, political, and environmental challenges, driving the widespread adoption of sustainable development as a solution. Engineers, crucial in shaping our world, must grasp the link between sustainability and their field. While Higher Education Institutes (HEI) have made significant strides in integrating sustainability into engineering programmes through various frameworks, challenges persist, and implementation varies across institutions.

This study aims to address the ongoing challenges of integrating sustainability into engineering education to achieve more consistent and effective outcomes across institutions. It involved interviews with 53 professionals from across Europe, including HEI leaders, engineering faculty, and industry representatives, to explore their approaches to incorporating sustainability, identify barriers, and assess the gap between current practices and industry needs. The insights from these interviews were then compared with existing research on the subject.

It is intended that the outcome of this work will help to equip HEI heads, lecturers, and other faculty staff with the knowledge and motivation to integrate Sustainable Development Goals (SDGs) into their courses, enhancing existing curricula and preparing graduates to address sustainability challenges, especially in light of global crises.

This study was undertaken as part of the EU Erasmus+ funded Engineering Education for a Sustainable Future (EESF) project. EESF is an international collaboration comprised of 7 partners working together to raise the standard and relevance of undergraduate engineering education (EQF 5-6) in order to better prepare future engineers to address the climate challenge and the sustainable development goals in their work. The overall research objectives include identifying, cataloguing, and appraising current approaches to sustainability education across European HEIs, highlighting the most effective ones in different engineering disciplines and identifying the gap between existing practice and what is needed.

01 Introduction

01 Introduction

1.1 Background and Context

Over the past decade, European Higher Education Institutions (HEIs) have made significant progress in integrating the Sustainable Development Goals (SDGs) into their curricula. Recognising their crucial role in promoting sustainable development, many institutions have proactively adjusted their practices to align with these global objectives. Building on this momentum, a European consortium comprised of 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 is now collaborating on the EU Erasmus+ funded project Engineering Education for a Sustainable Future (EESF). This initiative seeks to embed sustainability into engineering education, transforming lecture halls, laboratories, and classrooms across Europe.

In today's context of global crises, this mission has gained even greater urgency. HEIs are increasingly tasked with producing graduates who are not only technically proficient but also environmentally and socially conscious. This imperative is underscored by Sustainable Development Goal (SDG) 4, target 4.7, which envisions that by 2030, "all learners acquire the knowledge and skills needed to promote sustainable development." Additionally, European policy initiatives, such as the EU Green Deal, alongside national policies, reinforce the need for research focused on integrating sustainability into education. These policies have spurred the development of frameworks, guidelines, and toolkits to aid in this integration. Concurrently, industry and engineering associations are showing heightened interest in sustainable business models and the requisite sustainability skills.

Despite this momentum, the integration of sustainability into engineering programs remains inconsistent, varying from institution to institution (Leifler and Dahlin, 2020). While some HEIs adopt comprehensive, institution-led sustainability frameworks to systematically incorporate sustainability into their curricula, others take a more ad hoc approach (Aleixo et al., 2020). Furthermore, HEIs often encounter challenges or barriers to integrating sustainability into education, such as resource constraints, institutional inertia and the need for cultural change (Blanco-Portela et al., 2017; Leal Filho et al., 2018b; Serafini et al., 2022). There is a clear lack of consensus on the most effective strategies for implementing emerging international and national sustainable development frameworks into practice (Leal Filho, 2019).

Addressing these challenges demands strong leadership, innovative teaching methodologies, and active student engagement. Furthermore, studies by Begon et al. (2022), Leifler & Dahlin (2020), Natarajarathinam et al. (2021), Quelhas et al. (2019), and Thürer et al. (2018) highlight the urgent need for HEIs to adopt interdisciplinary strategies that integrate sustainability at the core of engineering education.

1.2 Sustainability Competences

Sustainability competences refer to the multifaceted sets of knowledge, abilities, and attitudes that support effective task completion and problem solving in relation to sustainability opportunities, challenges, and problems (Redman, et al., 2021). It is evident from reports by engineering accreditation associations such as Engineers Ireland and the UK's Engineering Council that engineering professionals are aware of their responsibility in contributing towards building a sustainable world and are actively engaging in work that educates, regulates and inspires the transition to a more sustainable society (Engineering Council, 2021; Engineers Ireland, 2022).

Previous literature has outlined the various technical and non-technical engineering skills that are relevant to sustainability (Rodriguez-Andara, et al., 2017). For example, in a study by Vehmaa, Karvinen, & Keskinen (2018), some of the core skills identified as a requirement for engineering professionals were specialised engineering skills like modelling skills, software proficiency, knowledge of Geographic Information Systems (GIS) and Information and Communication Technology (ICT) (Vehmaa, et al., 2018). Furthermore, a growing body of research has facilitated the categorisation of key sustainability skills into sustainability competence frameworks (Redman, et al., 2021). The Joint Research Centre (JRC), the science and knowledge service of the European Commission, developed the European sustainability competence framework known as GreenComp. GreenComp identifies a set of sustainability competences to be incorporated into educational programmes to support students' development of knowledge, skills, and attitudes that support ways to think and act with empathy, responsibility, and care for our planet (Bianchi, et al., 2022).

1.3. Building on Previous Work by UPM

EESF project partner UPM produced a paper called, 'Assessment of Global Competence of Engineers for a Sustainable World. Evidence from TA VIE Project' that presents a contemporary understanding of global competence for engineers from the perspective of European engineering companies and outlines the main findings in their Tools for Enhancing and Assessing the Value of International Experience for Engineers (TA VIE) project which was launched in 2018 (Ortiz-Marcos, et al., 2021). Global competence can be described as the skills, knowledge, attitudes, and behaviours necessary to prosper in a dynamic and complex world (Ortiz-Marcos, et al., 2021). The TA VIE project aims to quantify and evaluate the significance of global competencies and skills needed by engineering graduates who want to work in a multidisciplinary, global environment. This report will build upon UPM's work by highlighting and evaluating the competences specific to sustainability that are relevant for engineering students.

1.4. Research Aims

This paper will outline the current sustainability competences being taught in engineering courses and identify and appraise current approaches to sustainability education across European HEIs, highlighting the most effective strategies and identifying the gap between existing practice and what is needed. It is intended that EESF partners will employ the best practices and learnings identified in this research report to develop resources that engineering leadership and professors can use to embed sustainability into engineering education.

The objectives of this study are to:

1. **Identify** what, if any, sustainability competences are taught in HEIs.
2. **Outline** what practices are currently in use by HEIs to teach sustainability skills.
3. **Identify the strengths** of different practices employed by HEIs.
4. **Describe the deficiencies of certain practices** and whether the sustainability competences currently being taught effectively meet labour market expectations.

02 Methodology

02 Methodology

2.1 Introduction

This study employed a qualitative research design involving semi-structured interviews with a diverse group of stakeholders, including faculty, HEI leadership, vocational education and training providers (VETs), accreditation organisations, and industry representatives. This approach was selected to explore the complex and multi-faceted integration of sustainability competencies in engineering education from varied perspectives.

Qualitative research is particularly well-suited for studies focused on understanding the "why" and "how" behind processes and practices, emphasizing language and context over numerical data (Bell, 2010; Bryman, 2012). Semi-structured interviews were chosen for their flexibility, allowing interviewers to adapt questions to probe emerging themes and gather richer, more detailed insights. A thematic analysis of the data was conducted to systematically identify, organize, and interpret patterns within the qualitative data, ensuring a rigorous and comprehensive exploration of the research questions.

This methodology builds on and extends prior research conducted by UPM (Garrido Colmenero et al., 2021), with the aim of addressing the following objectives:
a) to identify what, if any, sustainability competencies are currently taught in HEIs,
b) to examine how these competencies are taught, and
c) to evaluate whether these competencies align with labour market expectations.

By employing this approach, the study seeks to provide actionable insights that can inform the design of engineering curricula, bridging gaps between educational practices and industry needs in advancing sustainability.

2.2. Data Collection

A total of 53 interviews were conducted by project partners ATU, UPM, P. Porto, IMTBS and WEI. A selective sampling strategy was employed in identifying interviewees for this study. The interviewees were a mixture of engineering faculty, HEI leadership, external stakeholders from vocational education and training providers (VETs), accreditation organisations and industry representatives. The figure below illustrates the breakdown of interviewees.

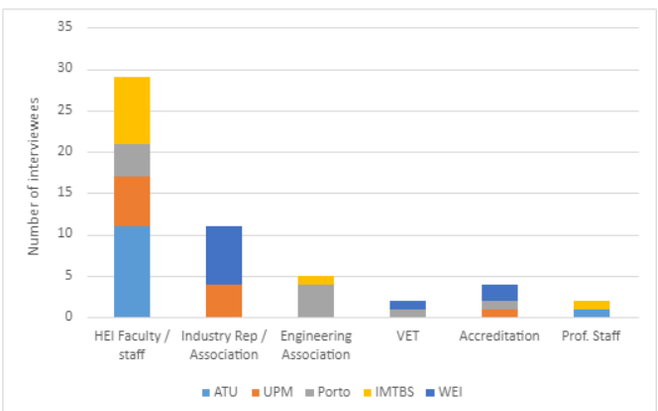


Figure 1: Breakdown of interviewees.

Interviewees provided their informed consent to take part in the study and were made aware of the procedure for gathering and storing data. Individuals' names were excluded from the report to protect their anonymity. Additionally, information about the goals, themes, and purpose of the research was provided to the respondents.

Semi-structured interviews were conducted for this research. This approach was employed as it allows for more in-depth discussions to occur and the opportunity to alter questions based on answers already provided or to better suit the interviewee. The interview questions were composed by IMTBS, informed by learnings from a literature review that was undertaken as part of the EESF project. Three sets of interview questions were prepared, tailored to three main target groups: engineering faculty, HEI leadership and other stakeholders.

2.3. Data Coding and Analysis

A thematic analysis of the gathered data was conducted, meaning the data were examined and coded to identify core themes that could be distinguished both between and within transcripts (Bryman, 2012; Braun & Clarke, 2006). Coding is a procedure used in the study of certain kinds of qualitative data in which the data are divided into component pieces and assigned labels (Bryman, 2012). The analyst then looks for instances of these coded text sequences within and across cases, as well as connections between various codes (Bryman, 2012). The analysis and interpretation of the data in this study resulted in the development of the main themes and in most instances, sub-themes. Project partners IMTBS and WEI split the coding and analysis of the 53 interviews and a combined coding spreadsheet was created to examine common themes. For the purpose of this Research Report, the codes generated from the questions targeted at engineering faculty and HEI leadership were analysed and grouped into themes.

The process of developing, refining, and applying codes was systematically documented in the shard coding spreadsheet. Examples of coded data and their corresponding themes were reviewed regularly to ensure they accurately represented the underlying data.

2.3. Research Ethics

Interviewees were informed about the protocol for collecting and storing data, and all interviewees provided their informed consent to participate in the study. To preserve their anonymity, the names of interviewees were left out of the report.

03 Results

03 Results

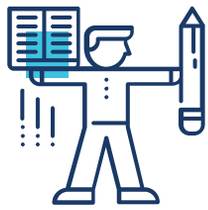
3.1 Introduction

The following section outlines the key findings from the interview analysis. To capture what sustainability competences are being taught in engineering programmes and the various ways HEIs are incorporating sustainability into engineering education, HEI leadership and engineering faculty interviewees were asked what sustainability skills their graduates possess and what inputs and activities are they employing to embed sustainability topics and initiatives, and the barriers or challenges associated with these actions. To identify the gaps between what HEIs are currently teaching and what industry needs, industry representatives were asked about the sustainability skills they look for in engineering graduates and the skills they believe HEIs should focus on improving.

Five main themes emerged from the interviews

01	**Approaches to embedding sustainability**	• Institutional • Departmental • Multidisciplinary
02	**Methods for integrating sustainability**	• Curriculum and Teaching Activities • Research and Outreach Activities • Technological Activities
03	**Barriers to incorporating sustainability**	• Logistical and Funding Difficulties • Lack of Interest or Motivation
04	**Current Sustainability Skills Being Taught in Engineering Courses**	• Technical Skills • Non-Technical Skills • Attitudes
05	**Industry perspective on sustainability skills needs**	• Technical Skills • Non-Technical Skills • Attitudes • Ideal Engineering Graduate • Skills Gaps • Industry Recommendations

3.3 Methods for Integrating Sustainability



Curriculum and Teaching Activities

Numerous strategies for how teaching staff can incorporate sustainability into engineering programs are offered. One of the most significant ways sustainability is included in engineering courses is through the redesign of course curricula to integrate sustainability into modules. In some cases, specific sustainability related modules were created such as sustainable urban drainage and renewable energy or a first year module introducing the SDGs. The development of sustainability related group projects, practical assignments, internships and competitions are also mentioned as practices for engaging students in sustainable thinking and delivering sustainable solutions. In particular, project-based learning is highlighted as a way to develop students' soft skills in teamwork, communication and presentation skills. In order to incorporate sustainability into their projects, students could be asked to use technical solutions that yield sustainable benefits. Practical assignments and internships or work placements are described as providing hands-on learning and real world exposure to sustainability practices. A few interviewees mentioned utilising contests or games to boost student interest in sustainability-related subjects, like hackathons. The advantages of having external speakers give lectures on current sustainability concerns in engineering was also raised.

Research and Outreach Activities

Participation in research projects and collaboration with external stakeholders and community members were mentioned by several respondents as beneficial ways to supplement academic activities for incorporating sustainability skills in engineering courses. Staff participation in research projects, external working groups and conferences are all mentioned as ways to progress sustainability in engineering education. An engineering faculty member from UPM described how their institution is a participant in the CESAER association which is an organization comprised of 58 universities globally. As part of this association, UPM have endorsed the "Contributions of Science and Technology Universities to Sustainability" declaration, emphasizing the centrality of sustainability across their university's mission in education, research, and management to address future challenges. European Union support through European alliances and university agencies were highlighted as assistance for developing sustainable initiatives. These alliances, such as the EULiST Alliance focus not only on academic excellence but also on connecting with society and businesses. Conducting site visits to examine case studies of sustainable engineering initiatives was recommended as an additional research activity.

Technological Activities

Additional resources like software and technologies are also used to teach sustainability skills in engineering programmes. Interviewees mentioned software, including digital SDG badges and the carbon accounting tool One Click LCA.

3.2. Approaches to Embedding Sustainability

Institutional

Although a variety of institutional inputs and activities for incorporating sustainability into engineering programmes were highlighted by this research, it is evident that the level of integration varies widely between institutions. Some faculty members at Politécnico do Porto (P. Porto) in Portugal, Universidad Politécnica de Madrid (UPM) in Spain and Institut Mines-Télécom Business School (IMTBS) in France report that the SDGs are widely integrated throughout their institutions. However, other reports from faculty members, including those from Atlantic Technological University in Ireland, suggest that while sustainability is integrated into courses, it is not done so consistently. Additionally, institutional level frameworks and processes for embedding sustainability across courses, which are influenced by international and national frameworks, are being utilised by some HEIs but not all. For example, UPM has established a Network of SDG Nodes, serving as Sustainability working groups and / or committees within the Schools and Faculty of the University. The engineering department actively participates in this initiative, with two members of the management team involved in the decarbonization committee.

One of the leading institutional level inputs which is highlighted in both current approaches to incorporating sustainability and considered integral for implementing future initiatives is funding. It is indicated that funding is required for the upskilling and training of university staff and for investment in on-campus environmental and sustainable initiatives such as waste recycling, carbon accounting and energy efficiency.

Some HEI faculty members also mentioned that engineering students are introduced to sustainability through institutional collaboration on projects that support the SDGs with communities, organisations, and businesses. For example, one interviewee mentioned that their university is involved in an institutional-level group called "Développement Durable – Responsabilité Sociétale et Environnementale", a cross-disciplinary group, that has worked on sustainability within research, teaching and administration focussing on decarbonisation, mobility, energy sobriety, etc.

Departmental

Although institutional inputs are mentioned by most participants, there was indication by some that embedding sustainability is influenced more so by department staff than at the institution level. Efforts from department faculty were highlighted as being instrumental in encouraging the incorporation of sustainability into engineering programmes through the integration of sustainability frameworks and by referencing SDGs in programme development. A few interviewees mentioned individual faculty members who were passionate advocates about sustainability as instrumental in developing sustainable initiatives such as collaborating with industry on sustainability research projects. One interviewee from ATU mentioned that they developed training for staff and received departmental support for continuing professional development (CPD) courses on sustainability. This indicates however that sometimes a solitary effort is provided by individuals in embedding sustainability within the department.

Multidisciplinary

A variety of benefits to a multidisciplinary approach to incorporating sustainability were also discussed. The interviewees highlighted several advantages of collaboration between schools and disciplines, such as the generation of well-rounded graduates through knowledge exchange across disciplines, the ability to address multiple Sustainable Development Goals (SDGs) more effectively, the enrichment of the learning process through the incorporation of diverse perspectives, and the enhancement of curriculum relevance leading to comprehensive solutions. Another interviewee noted that interdisciplinary collaboration allows students to develop a holistic understanding of the environmental implications of technology advancements.

3.4 Barriers to Incorporating Sustainability

Logistical and Funding Difficulties

A number of barriers to implementing current and future sustainability activities into engineering programmes were discussed. The most frequently cited challenges or barriers to embedding sustainability are a lack of funding, the need for additional training, limited space in curricula, difficulty in modifying existing modules and courses, especially in highly specialised fields, and time constraints.

Lack of Interest or Motivation

Apart from the aforementioned logistical and funding difficulties, a lack of motivation amongst HEI staff and students was cited by some as a barrier to incorporating sustainability in engineering education. Often HEI staff have competing priorities and limited resources for delivering course material, therefore, there is sometimes a reluctance to change programme content. Differing pedagogical views among lecturers can also present problems with revising course material. It was mentioned by respondents that students can lack a deep conviction about sustainability, therefore, this lack of interest from students can hinder the impact of programme revisions.

3.5 Current Sustainability Skills Being Taught in Engineering Courses

Technical skills

Interviewees discussed how engineering programmes teach a wide range of technical skills and competences that are relevant for sustainability. Many acknowledged that engineering students gained a basic understanding of key sustainability principles in university, however, only a limited number of interviewees mentioned that students left university with an in dept knowledge of sustainability related legislation and regulation or how to consider sustainability in engineering projects. There were a number of references to the importance of students having an understanding of financing and the economic impacts of engineering decisions, however, it is unclear how sufficiently this is currently being taught in universities. It also appears that a student's engineering field will determine what kinds of engineering-specific skills they can apply to sustainability topics or issues. For example, structural or civil engineering students are taught about energy performance, calculating the lifecycle cost of building materials and reducing environmental footprint of project. More universal skills for engineering students that aren't specific to their field include data analysis, digital modelling and the ability to use mathematical tools, models and softwares. There were many references to students developing analytical and cognitive skills such as critical thinking, systems thinking and forward-thinking design. One competence amongst engineering graduates which was noted as being lacking by many interviewees was practical experience of working on real life engineering projects.

Non-Technical Skills

Interviewees also observed that engineering students were being taught a wide range of non-technical skills. Teamwork skills, strong communication and experience in collaborative work and stakeholder engagement were all referenced as skills that engineering students develop during their time in university. It was noted that leadership and project management skills are also cultivated in many engineering programmes including students' ability to explain and defend their decisions. Creativity was also highlighted as an important skill for engineers to obtain in order to develop engineering solutions to sustainability problems.

Attitudes

Besides technical and non-technical skills, certain attitudes of students were noted as important to developing engineering students' sustainability competences. Passion or concern about sustainability issues and ambition to solve these problems was frequently referenced throughout the interviews. Flexibility and adaptability were also highlighted as attitudes or skills that engineering students are encouraged by HEIs to possess.

3.6 Industry Perspective on Sustainability Skills Needs

Understanding the competencies that employers look for in graduates is crucial to assessing the success of strategies and tactics used to integrate sustainability into engineering programs. Industry representatives interviewed as part of this research projected outlined various technical skills, non-technical or transversal skills and attitudes that they consider ideal engineering graduates should have, which are discussed in this section. The main skills gaps identified by industry representatives among recent graduates will then be discussed, along with suggestions for how HEIs can close these gaps.

Technical Skills

When discussing the variety of skills that graduates should possess, it was clear that industry members consider strong technical skill to be of utmost importance. Adequate technical competencies are necessary to quickly understand and implement directions to handle daily tasks and projects. Some of the technical skills related to sustainability include waste management, eco-design, and the incorporation of energy efficiency and circular economy principles in the designing of projects such as calculating the lifecycle cost of building materials and carbon footprint of projects. To grasp the multiple dimensions and develop resilient strategies, the interviewees highlighted various approaches to thinking, including critical thinking on complex issues, the use of systematic analysis, and the application of foresight. There were also references to incorporating cutting-edge technologies and methodologies such as artificial intelligence, digital modelling and tools such as Life Cycle Assessment (LCA) and Global Reporting Initiative (GRI). It is noted that the need to develop technology that meets new sustainability requirements means that students must go beyond traditional engineering and functional criteria. It is also mentioned frequently that understanding the sustainable development goals and pertinent national and European legislation is essential for engineering students. This includes knowledge of the planning system and legal requirements of engineering projects

Non-Technical Skills

While although technical skills are considered critical for graduates to possess, non-technical or transversal skills are also deemed important by industry members. Most of the non-technical skills mentioned are not unique to sustainability but they are beneficial for incorporating sustainability into projects and delivering sustainable solutions. Communication, public speaking and persuasion skills, particularly the ability to describe complex engineering principles into more simple terms is outlined as important for project work and stakeholder engagement. Organisational abilities, project management, and leadership are also highlighted as desirable qualities in engineering graduates. Additionally, sustainability is frequently cited as requiring adaptability, agility, and change management abilities due to the ever evolving nature of the field. Furthermore, engineering solutions to sustainability issues are seen to require creativity and innovation.

WEI 6:

'Engineers are put in a position where they're put in a highly stressed and challenging environment typically, which means that they're under pressure to deliver complex solutions with limited resources. The best way you can do that, the only way you can do that, is with teamwork.'

"I suppose, the future workforce is going to be about adaptability and change and being able to be agile because there's going to be a lot of disruption due to technology. So it's about how to leverage off that."

Attitudes

Alignment with industry values and attitudes are also considered critical for engineering students. Positivity and passion about sustainability is described as inspiring dedication in delivering sustainable challenges. One interviewee noted that salaries in sustainable industries are often less than other fields, therefore, passion in sustainability is important to attract and sustain employees. An aptitude for lifelong learning and a willingness to work hard are also noted as admiral qualities for graduates to possess

Ideal Engineering Graduate

When asked what qualities an ideal graduate should have, industry representatives listed several core competencies. According to respondents, an ideal graduate would have strong knowledge of engineering fundamentals with practical training and a basic understanding of sustainability and relevant legislation. An ability to incorporate sustainability in engineering designs and to use technical engineering skills in solving sustainability problems is also emphasised. Key non-technical skills include communication, problem-solving, and leadership. Additionally, graduates should also be passionate and dedicated to addressing engineering challenges.

Skills Gaps

Although it is evident from the interviews that HEIs are actively incorporating sustainability into engineering programmes, industry representatives noted that some skills gaps remain between what HEIs are teaching and what is required by industry. It was noted by some interviewees that current engineering graduates have strong theoretical knowledge but often don't have experience of applying that knowledge to real world situations. Additionally, it was discussed how engineers sometimes focus too heavily on the technical aspects of regulations, making it challenging to navigate the bureaucratic side, such as understanding the differences between regulations and directives. It was also observed that certain soft skills, like expressing ideas succinctly and clearly, needed improvement.

WEI 6:

'And I'm finding that rather than having to provide experience to graduates, I actually have to do a hell of a lot of training. Some of them don't have the basic concepts that are required to grasp the technical issues we need to undertake now.'

Industry Recommendations

A variety of recommendations on how HEIs can better provide sustainability skills and competencies to engineering students were provided by interviewees. It was indicated that greater integration of sustainable development across engineering disciplines should be implemented at an institutional and systematic level and more should be done to shift educators' mindsets to prioritise sustainable development alongside technical skills. One of the main suggestions provided by industry is that universities should strike a balance between teaching foundational concepts and providing practical, industry-relevant skills through a collaborative approach wherein industry partners play a role in redesigning engineering programmes and facilitating work placement and real-world engineering projects. Project based learning is particularly emphasised for teaching communication skills and for understanding diverse perspectives which can help with driving innovation and problem-solving. It was also suggested that HEIs provide more careers guidance on identifying what jobs and companies are hiring engineers with sustainability skills and they run a mentorship initiative between students and alumni. Conferences and seminars are also suggested as initiatives for increasing students' engagement with sustainability topics.

3.7 Conclusion

All educational professionals interviewed indicated that attempts have been made to embed sustainability in some way, however, embeddedness is not standardised across courses. Increasing national and EU legislation, industry demands for sustainability skills, accreditation requirements and rising student interest in sustainability all provide further incentive for HEIs to improve the incorporation of sustainability in engineering education.

04 Discussion

04 Discussion

4.1 Introduction

This chapter discusses in more detail the findings presented in Section 3 and contextualises these findings within the framework of existing research. A comparison of the results with earlier work revealed a number of important strategies for incorporating sustainability as well as a number of implementation hurdles.

4.2 Approaches to Embedding Sustainability

Institutional Approaches

In order to adequately support sustainability initiatives within universities, institutional policies and governance structures are essential. Our findings show that HEIs that have established frameworks or processes to incorporate sustainability at an institutional level are able to implement sustainability more systematically. This is in line with previous research which indicates that currently a small percentage of HEIs have implemented whole-institution strategies for sustainable development and those that have incorporated institutional level frameworks contributed more significantly towards achieving the sustainable development goals (Mader & Rammel, 2015; UNESCO 2017b; Eppinga, et al., 2019). UPM have established committees or offices specifically dedicated to sustainability, whose job it is to create and carry out strategic sustainability plans. According to earlier studies, initiatives like this help to supervise how sustainability principles are incorporated into institutional practices, policies, and decision-making procedures in order to guarantee sustained commitment to sustainability objectives (Leal Filho et al., 2021; Serafini et al., 2022; Weiss et al., 2021). The findings also indicate that institutions that don't have sustainability frameworks often integrate sustainability in fragmented or partial ways such as isolated sustainability focused modules or occasional project work. Similar findings by Wyness et al. (2015) showed that HEIs without frameworks are frequently limited to offering supplemental courses to their existing curricula. It appears that departmental faculty members bear a large portion of the responsibility for integrating sustainability into engineering education. It is therefore evident that fostering a culture of sustainability throughout all aspects of university operations requires the strategic integration of SDGs into institutional policies and practices.

Multidisciplinary Approaches

Our findings highlight the significance of multidisciplinary approaches and the necessity for HEIs to collaborate across departments and with external stakeholders in order to address the complex nature of sustainability challenges. According to Quelhas et al. (2019), the justification for incorporating the Sustainable Development Goals (SDGs) into engineering programs through multidisciplinary approaches is based on the understanding that sustainability concerns are intricate and interrelated. Fostering collaboration across departments and faculties, dismantling silos and promoting a transdisciplinary approach to sustainability education and research, as well as facilitating partnerships and knowledge sharing between institutions worldwide, are crucial for advancing the implementation of the SDGs in Higher Education Institutions (Moon, 2018; Leal Filho et al., 2021). Interdisciplinary research projects and classes can also teach engineering students about the connections between the SDGs and how to collaborate across disciplines to develop original solutions (Quelhas et al., 2019; Ramirez-Mendoza et al., 2020).

4.3 Methods for Integrating Sustainability

Curriculum and Teaching Activities

Universities are increasingly realising the value of incorporating sustainability principles into their curricula, as evidenced by the findings in this report and earlier studies (Barth, 2014; Leal Filho et al., 2021; Serafini et al., 2022; Weiss et al., 2021). Research indicates that adding concepts, challenges, and processes related to sustainability to engineering programmes can be accomplished by creating new courses or updating current ones to specifically address sustainability issues that are pertinent to engineering disciplines (Beagon & Bowe, 2023; Beagon et al., 2022). Interviewees emphasised the use of active learning techniques, such as project-oriented and problem-based assignments, study visits, and educational games, as effective teaching strategies. These approaches have also been mentioned in previous studies (Beagon et al., 2022; Quelhas et al., 2019; Tejedor et al., 2019; Thürer et al., 2018).

Research and Outreach Activities

Research projects and initiatives involving sustainability were highlighted by interviewees from numerous institutions, as well as in existing literature, as another strategy for increasing the representation of sustainability in engineering education (Leal Filho et al., 2021). Collaborative research partnerships among government agencies, industry, and academia promote significant advancements towards sustainable solutions and enable the transfer of knowledge (Leal Filho et al., 2021; Serafini et al., 2022). Similarly, university outreach programmes and collaborations with businesses, NGOs, local government and communities have been highlighted as a way to enable engineering students to use their knowledge and abilities to tackle practical sustainability issues (Bielefeldt et al., 2019). According to Bielefeldt et al. (2019), these practical learning opportunities not only improve students' comprehension of the SDGs but can also help them develop social awareness and a feeling of civic duty.

Emerging Technologies

The integration of emerging technologies, such as artificial intelligence (AI), the Internet of Things (IoT), and blockchain, should be emphasized as part of the curriculum for sustainability in engineering education. These technologies offer innovative solutions for sustainability challenges, from resource optimization to transparent and traceable sustainability practices. Including them in engineering programs can provide students with the tools to address complex sustainability issues in modern industries and infrastructure.

4.4 Barriers and Limitations to Integrating Sustainability

While embedding the SDGs in engineering courses offers numerous benefits, it also presents challenges and considerations. Financial constraints, insufficient resources and training, institutional inertia, and a lack of interest, or concern from faculty and or students are the main barriers to integrating sustainability mentioned in the interviews and in existing literature (Chang and Lien, 2020; Blanco-Portela et al., 2017; Leal Filho et al., 2018b; Serafini et al., 2022). To increase faculty engagement in teaching sustainability, it is recommended in the literature that staff receive the necessary training and assistance to integrate the sustainability into their courses and assessments (Beagon et al., 2022; Serafini et al., 2022; Weiss et al., 2021). The effective integration of the SDGs into academic programs and their delivery in the classroom, however, can be significantly hampered by universities' inability to offer this training due to budgetary limitations and a lack of resources (Blanco-Portela et al., 2017; Leal Filho et al., 2018b; Leifler & Dahlin, 2020; Serafini et al., 2022). Organisational challenges are also identified as a significant obstacle to introducing sustainability. Research by Serafini et al. (2022) outlines the disparity in SDG-related course content among academic institutions and recommends that department heads be given the authority to carry out coordinated initiatives that involve the entire institution. Additionally, Serafini et al. (2022) highlights how curriculum rigidity in universities can impede the dissemination of the SDGs. It is evident from the literature and findings from this study that transformative change is required in university leadership and organisation to strategically embrace the sustainable development goals.

4.5 Current Sustainability Skills Being Taught in engineering Courses

The findings of this study suggest that while technical skills are paramount for engineering students, improvements can be made in increasing students' knowledge of problem solving and critical thinking on sustainability related engineering projects. Furthermore, improvements in the understanding of relevant legislation and practical experience should be incorporated in programme revisions. Certain non-technical skills which feature in this study and in previous research as integral competencies for graduates include strong communication, leadership and project management skills (Adams et al., 2020; Beagon & Bowe, 2023; Beagon et al., 2022; Desha et al., 2019).

Apart from the technical and non-technical abilities, learning outcomes that are not specifically mentioned in the formal curriculum can result from faculty members' unintentional teaching or communication of attitudes, knowledge, and behaviours to students—a phenomenon known in the literature as the "hidden curriculum" (Beagon et al., 2022; Trevelyan, 2019). Passion, dedication and positivity are referenced several times by HEI staff and industry members as important attitudes or values for both students and teaching staff to possess. Furthermore, the literature proposes that a faculty with a strong commitment to sustainability and knowledge of its principles will be better equipped to incorporate it into the curriculum and impart it to students in the classroom, as academic beliefs have a sizable impact on educational reform (Chan & Luk, 2022).

In addition to the technical and non-technical skills already discussed, Futures Thinking and anticipatory competencies are gaining recognition as essential for addressing future sustainability challenges. These competencies, as outlined in GreenComp, involve the ability to envision and prepare for long-term sustainability scenarios, evaluate potential outcomes, and make decisions that will have a positive and lasting impact. Futures Thinking encourages students to think critically about the future implications of current decisions, particularly within the context of engineering projects and sustainability. This mindset complements problem-solving and critical thinking skills, preparing students to anticipate and mitigate future challenges, which is increasingly vital in a world facing complex environmental, economic, and social issues.

05 Conclusion

05 Conclusion

5.1 Introduction

The following section offers an overview of the key insights drawn from this research and their alignment with the report's objectives. Additionally, it presents recommendations for enhancing the integration of sustainability into engineering education within Higher Education Institutions.

5.2. Research Objective 1

Objective 1:
What, if any, sustainability competences are taught in HEIs.

It is evident from the findings that all of the HEIs interviewed are attempting to produce engineering graduates with the technical and non-technical skills that will enable them to effectively consider and incorporate sustainability in engineering projects. The key technical skills identified range from knowledge of sustainability principles and relevant legislation to specific engineering skills such as modelling and mathematics, to cognitive abilities such as systems thinking and critical thinking. Various soft skills like communication, teamwork and leadership are all highlighted as important skills that HEIs are currently trying to develop in students. Moreover, attitudes such as positivity and passion, whilst not being actively taught in engineering programmes, are acknowledged by HEI staff and industry members as being integral. However, the various approaches used to integrate sustainability into courses and develop sustainability competencies in students, as well as the opportunities and obstacles faced by institutions and engineering departments, appear to determine how successful HEIs are in producing ideal engineering graduates.

5.3 Research Objective 2

Objective 2:
Outline what practices are currently in use by HEIs to teach sustainability skills

Universities are increasingly realising the value of incorporating sustainability principles into engineering courses. The findings highlight several strategies for incorporating sustainability into engineering programmes including redesigning course curricula, developing sustainability-related group projects, practical assignments, internships, and competitions, and having external speakers give lectures on current sustainability concerns. Participation in research projects, external working groups, and conferences can supplement academic activities for incorporating sustainability skills in engineering courses. Furthermore, engineering students are introduced to sustainability through institutional collaboration on projects supporting the Sustainable Development Goals (SDGs) with communities, organisations, and businesses. European Union support through alliances and university agencies can also help develop sustainable initiatives. Finally, additional resources like software and technologies, such as digital SDG badges and carbon accounting tools are used to teach sustainability skills in engineering programmes.

5.4 Research Objective 3

Objective 3:
Identify the strengths of different practices employed by HEIs

Institutional policies and governance structures are crucial for supporting sustainability initiatives within universities (HEIs). Frameworks and processes for embedding sustainability across courses are influenced by international and national frameworks, however how these frameworks are developed and integrated is not consistent. Mechanisms such as institutional committees or working groups are examples of approaches for supervising the integration of sustainability principles into institutional practices, policies, and decision-making procedures. Evidence suggests that institutions with established sustainability frameworks can implement sustainability more ally, contributing more significantly to achieving the sustainable development goals. Conversely, institutions without sustainability frameworks often integrate sustainability in fragmented or partial ways, with departmental faculty members bearing a significant responsibility.

Multidisciplinary approaches are also highlighted as essential for addressing sustainability challenges, fostering collaboration across departments and external stakeholders. Interdisciplinary research projects and classes can teach engineering students about the connections between the Sustainable Development Goals (SDGs) and how to collaborate across disciplines to develop original solutions.

While multidisciplinarity is an essential starting point for addressing complex sustainability challenges, there are emerging calls for a shift towards interdisciplinarity and ultimately transdisciplinarity. Transdisciplinarity moves beyond integrating knowledge from different disciplines by actively engaging diverse stakeholders—students, community groups, NGOs, and civil society—in collaborative problem-solving processes.

This approach challenges traditional university structures and fosters innovative solutions that align with real-world complexities. Transdisciplinary practices enable engineering education to transcend academic silos, driving transformative changes necessary for achieving the 2030 Agenda. Future efforts should prioritize embedding transdisciplinarity into curricula, governance structures, and external partnerships.

Collaborative research partnerships among government agencies, industry, and academia promote significant advancements towards sustainable solutions and enable knowledge transfer. University outreach programmes and collaborations with businesses, NGOs, local government, and communities enable engineering students to use their knowledge and abilities to tackle practical sustainability issues, improving their comprehension of the SDGs and developing social awareness and civic duty.

To further strengthen the integration of sustainability into engineering education, universities should establish formal partnerships with key industry players. These collaborations could focus on creating co-op programs or internships that specifically address sustainability projects. By involving students in real-world sustainability challenges, these partnerships offer valuable hands-on experience and better prepare students for industry expectations. This can bridge the gap between academic learning and professional practice, enhancing students' understanding of sustainability in a practical context.

To better prepare students for real-world sustainability challenges, it is crucial to increase the number of project-based learning opportunities within the curriculum. This could include capstone projects, hackathons, or collaborations with local communities on sustainability challenges. These types of projects help students apply theoretical knowledge in practical, real-world settings, fostering critical thinking, problem-solving, and innovation.

5.5 Research Objective 4

Objective 4:
Describe the deficiencies of certain practices and whether the sustainability competences currently being taught effectively meet labour market expectations.

Integrating Sustainable Development Goals (SDGs) into engineering courses presents challenges such as financial constraints, insufficient resources, institutional inertia, and lack of interest from faculty and students. To increase faculty engagement, it is recommended that staff receive necessary training to integrate sustainability into their courses and assessments. However, universities may struggle to offer this training due to budgetary limitations and lack of resources. Organisational challenges, such as disparity in SDG-related course content among institutions, also hinder the effective integration of sustainability. Encouragement of student-led sustainability initiatives could be a low cost way of enhancing engagement.

Industry representatives suggest that an ideal graduate should have strong knowledge of engineering fundamentals, practical training, understanding of sustainability, and the ability to incorporate sustainability into designs. Non-technical skills like communication, problem-solving, and leadership are also important. However, the findings suggest that there are skills gaps between what is taught in HEIs and industry requirements, with current graduates lacking practical experience and having deficiencies in some soft skills.

As the report indicates, there is a need to assess students' sustainability competencies more effectively. To address this, universities should develop specific assessment tools and feedback mechanisms that evaluate students' understanding and application of sustainability concepts. These tools should be integrated into both academic and extracurricular activities, ensuring that students are held accountable for their sustainability skills and competencies.

5.6 Recommendations

The findings of this study underscore the critical importance of institutional frameworks and multidisciplinary approaches in effectively embedding sustainability within higher education institutions. By addressing implementation challenges and fostering collaboration, universities can enhance their contributions to sustainable development goals and better prepare students for future sustainability challenges. This report highlights the significance of governance structures in establishing a foundational support system for the integration of the Sustainable Development Goals and in aligning institutional frameworks with those goals. Revision of curricula is required in order to teach SDG-related ideas across subject areas which should promote interdisciplinary learning and help develop students' critical thinking abilities. The findings also emphasise the critical role that multidisciplinary outreach and research play in generating creative solutions to sustainability issues and interacting with the public to support sustainable practices.

Interviewees suggested that Higher Education Institutions (HEIs) should integrate sustainable development across engineering disciplines and shift educators' mindsets to prioritise sustainable development alongside technical skills. They suggested a collaborative approach, balancing foundational concepts with practical skills, project-based learning, career guidance, mentorship, and conferences to increase students' engagement with sustainability topics.

It is also essential to support faculty members by developing comprehensive faculty development programs. These programs should encompass workshops, certifications, and continuous professional development opportunities that focus on the latest sustainability practices and pedagogical strategies. By ensuring that faculty members are equipped with up-to-date knowledge and teaching methodologies, universities can enhance their ability to integrate sustainability into their courses effectively.

To increase student interest and participation in sustainability, universities should establish student-led sustainability initiatives, such as clubs and organizations focused on environmental or sustainability challenges. Coupled with incentives like awards, recognition, or funding for outstanding sustainability projects, these initiatives can significantly enhance student engagement. Encouraging student ownership of sustainability projects fosters a deeper commitment to the cause and supports the development of leadership and problem-solving skills.

Additionally, it is recommended that industry partners play a role in redesigning engineering programmes and facilitating real-world projects.

Lastly, to measure the long-term impact of sustainability integration in engineering education, it is recommended to conduct longitudinal studies that track the career progression of graduates and their contributions to sustainability in their professional roles. This would provide valuable data on how effectively sustainability education translates into real-world impact and could inform future curriculum improvements.

By adopting these strategies, HEIs can not only embed sustainability more deeply into their curricula but also equip students with the skills and mindset needed to address the complex challenges of a sustainable future.

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