Engineering Education for a Sustainable Future

Engineering Education for a Sustainable Future: Discovery Report

Co-funded by the Erasmus+ Programme of the European Union

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Abbreviations

EESF	Engineering Education for a Sustainable Future
SDGs	Sustainable Development Goals
COP26	26th UN Climate Change Conference
EU	European Union
EGD	European Green Deal
UN	United Nations
EEA	European Environment Agency
HEIs	Higher Education Institutions
ESD	Education for Sustainable Development
IMTBS	Institut Mines-Télécom Business School
ATU	Atlantic Technological University
UPM	Universidad Politecnica de Madrid
P. Porto	Instituto Politecnico do Porto
WEI	Wind Energy Ireland
UTT	Université de Technologie de Troyes
IMT	Institut Mines-Télécom

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Executive Summary

The world today is facing a number of **complex, interconnected environmental, societal, and economic challenges**, which are currently being tackled under the direction of a number of sustainability-related initiatives such as the United Nations Sustainable Development Goals (SDGs), the European Green Deal (EGD), and the 26th UN Climate Conference (COP26). While progress is being made in a number of areas, **there remains much work to be done**, and this work can be expected to continue for some time. To address these global challenges, **new generations of leaders and skilled professionals** who will be able to drive needed change, **must be continuously developed**.

Engineering is one of the most important sustainability-relevant sectors, and due to this, **future engineers will have an enormous influence on the way our world is shaped** and the resources we use. In recognition of this, the **Engineering Education for a Sustainable Future (EESF) project** was created with the aim of **better equipping engineering students to address societal challenges** and contribute to the realisation of European and global sustainability agendas. To achieve this aim, the project focuses on the development of practical tools and resources for engineering educators so that they are better equipped to integrate sustainability competences into engineering curricula. The *Engineering Education for a Sustainable Future: Discovery Report*, is meant to provide the EESF Project consortium with a foundation of knowledge upon which educational resources can be constructed.

Key Messages of the Discovery Report

Embedding Sustainability into Engineering Education is Essential to Addressing Global Challenges

Engineering solutions are identified as crucial for addressing sustainability-related targets, with a UNESCO report stating, for example, that each of the 17 SDGs will require engineering solutions in some fashion (UNESCO, 2021). By integrating sustainability into engineering education, we can ensure that future engineers understand their role in making progress towards sustainability goals, and that they are equipped with the knowledge and skills to make this progress.

Sustainability is Not Currently Being Embedded into Engineering Education in a Consistent Way

Research carried out for the *Discovery Report* reveals that while engineering programmes have begun embedding sustainability, implementation varies significantly across regions, countries, and even within institutions, with no standardized methodology in place. Despite positive student perceptions about sustainability and SDGs, there are notable gaps in their knowledge and practical application skills, resulting in a misalignment between educational practices and job market competency requirements.

Recommendations to Better Integrate Sustainability into Engineering Education

Based on information collected for the report, and inspired heavily by the framework created in the **Engineering for One Planet initiative**, the *Discovery Report* includes three principle recommendations which are based on a simplified framework for embedding sustainability into engineering education (Figure 1 below).

Figure 1: A Simplified Framework for Embedding Sustainability into Engineering Education

Source: *Authors' Visualisation*

| Recommendation 1: Develop Sustainability-Oriented Mindsets in Students

Sustainability-oriented mindsets involve cultivating attitudes that enable engineers to address sustainability challenges proactively. While technical competencies are essential, an engineer's ability to **think critically about sustainability problems, collaborate across disciplines, and consider ethical implications** is just as crucial. The Discovery Report highlights three key mindsets that engineering educators should cultivate in students:

- **Systems Thinking** – Engineering solutions do not exist in isolation; they interact with social, environmental, and economic systems. Educators should teach students to analyze sustainability challenges holistically, understanding cause-and-effect relationships, unintended consequences, and trade-offs in engineering decisions.
- **Multidisciplinarity** – Sustainability challenges often require collaboration across engineering disciplines (e.g., civil, mechanical, electrical) as well as with fields like business, policy, and environmental science. Engineering programs should encourage interdisciplinary projects, coursework, and research that expose students to diverse perspectives and problem-solving approaches.
- **Ethical Mindset** – While ethics courses are already well-integrated into many engineering programs, sustainability introduces new ethical considerations, such as environmental justice, corporate responsibility, and resource distribution. Educators should guide students to reflect on the broader impact of their work and incorporate sustainability as a core ethical responsibility in engineering practice.

By embedding these mindsets into coursework, case studies, and project work, educators can ensure that students approach sustainability with **a critical and ethical lens, rather than seeing it as an add-on to technical skills**.

| Recommendation 2: Integrate Comprehensive Sustainability Knowledge Across Engineering Curricula

Sustainability in engineering education must go beyond technical fixes to include **broad-based knowledge** that enables students to understand the complex challenges they will face in their careers. The Discovery Report identifies several key knowledge areas that should be systematically integrated into engineering curricula:

- **The Foundations of Sustainability** – Engineering students should develop a strong theoretical understanding of sustainability, including the historical development of sustainability concepts, the Sustainable Development Goals (SDGs), and their relevance to engineering practice.
- **Environmental Sustainability Knowledge** – Courses should cover renewable energy, energy efficiency, sustainable materials, circular economy principles, life cycle assessments (LCA), and pollution control technologies. These topics help students assess the environmental impacts of engineering solutions.

- **Economic and Business Perspectives on Sustainability** – Sustainability is not just a technical issue; it is also a business and economic challenge. Students should learn about corporate social responsibility (CSR), sustainable supply chains, the financial viability of green technologies, and policy incentives for sustainability.
- **Social and Ethical Dimensions of Sustainability** – Engineers must consider the social implications of their work, including environmental justice, resource equity, and the cultural impacts of technology development. These topics should be woven into engineering case studies and ethical discussions.
- **Sustainability in Engineering Standards and Regulations** – Understanding environmental laws, green building certifications, and industry sustainability standards (such as LEED, ISO 14001, and EU Green Deal policies) is essential for engineering students entering the workforce.

By embedding **comprehensive sustainability knowledge** into engineering education, students will be **better equipped to make informed, responsible engineering decisions** in their careers.

| Recommendation 3: Train Students in Sustainability-Related Skills

Developing sustainability-related skills is crucial for preparing students to apply their knowledge in real-world engineering contexts. The Discovery Report identifies two categories of skills that engineering programs should prioritize:

Technical Sustainability Skills

These are the discipline-specific skills needed to implement sustainability in engineering solutions, including:

- **Life Cycle Analysis (LCA)** – Assessing the environmental impact of materials, processes, and products over their entire life cycle.
- **Sustainable Materials Selection and Design** – Choosing low-impact materials and designing for durability, recyclability, and minimal waste.
- **Pollution Prevention and Waste Management** – Applying circular economy principles to minimize waste and maximize resource efficiency.
- **Digital and Analytical Tools for Sustainability** – Using **GIS mapping, carbon accounting software, and environmental modelling tools** to support sustainability assessments.

Transversal (Non-Technical) Sustainability Skills

These skills enable engineers to work effectively in sustainability-related roles across industries and include:

- **Collaboration and Multidisciplinary Teamwork** – Working with professionals from different fields to develop integrated sustainability solutions.
- **Problem-Solving and Critical Thinking** – Analysing sustainability challenges from multiple angles and developing innovative solutions.
- **Leadership and Advocacy for Sustainability** – Encouraging students to take initiative in sustainability projects, whether in academia, industry, or policy.
- **Effective Communication of Sustainability Concepts** – Being able to explain complex sustainability issues to technical and non-technical audiences, including policymakers, business leaders, and the general public.

By emphasizing both **technical** and **transversal** skills, educators can ensure that engineering graduates **are not only knowledgeable about sustainability but also capable of implementing sustainable solutions effectively**.

Approaches to Embed Sustainability-related Mindsets, Knowledge, and Skills

Many examples of how to effectively embed sustainability into engineering education by developing sustainability-related mindsets, knowledge, and skills in students were highlighted in the Discovery Report. Often, these help educators simultaneously implement all three recommendations mentioned above. These appraoches include:

- **Project-Based Learning** – Assigning students real-world sustainability challenges where they must apply both theoretical knowledge and problem-solving skills.
- **Experiential Learning and Industry Collaboration** – Partnering with companies, municipalities, and NGOs on sustainability projects where students gain hands-on experience in applying sustainable engineering principles.
- **Case Studies and Policy Analysis** – Encouraging students to critically analyze real-world engineering projects, focusing on their sustainability successes and failures.
- **Multidisciplinary Learning Environments** – Creating courses that bring together students from engineering, business, environmental science, and social sciences to collaborate on sustainability problems.
- **Mentorship and Professional Development Opportunities** – Connecting students with sustainability professionals through mentoring programs and career development initiatives.

By embedding sustainability-oriented mindsets, knowledge, and skills into engineering education, we can **empower future engineers to become proactive agents of change in addressing global challenges**. The information and recommendations in the *Engineering Education for a Sustainable Future: Discovery Report* offer a structured framework for educators to equip students with the competencies needed to develop innovative, ethical, and multidisciplinary solutions.

As sustainability continues to shape industries, policies, and societies, engineering education must evolve to meet these demands, and the **Engineering for a Sustainable Future project** aims to facilitate this evolution.

01 Introduction & Background

The Engineering Education for a Sustainable Future (EESF) project aims to develop and implement innovative learning and teaching practices in engineering education across four Higher Education Institutions (HEIs) in Europe, aligned with the 2030 Sustainable Development Goals (SDG) framework. The project seeks to better equip engineering students to address societal challenges and contribute to the realisation of European and global sustainability agendas, including the SDGs. EESF will address the need for HEIs to integrate sustainability competences into their curricula, ensuring that future engineers can develop innovative solutions for societal challenges.

The research produced by this stage of the EESF project will be used to inform the development of Online Educational Resources (OERs) to equip engineering faculties with the tools to embed sustainability in their programmes, upskill teaching staff to teach transversal competences, and provide flexible, evidence-based teaching materials. In doing so, the project responds to industry demands for graduates who can integrate sustainability and the SDGs into engineering projects, as well as contribute to a fair, just, and sustainable society. Further, EESF aims to foster innovative learning practices, improve education quality and relevance, and promote sustainability and civic engagement for engineering students.

In order to meet these goals of the EESF project, it is essential to outline the relationship between engineering and the sustainability agenda as well as the ways in which engineering higher education prepares its students to work within this intersection. In this Discovery Report, we outline in detail the Sustainability Agenda as framed by the UN 2030 Agenda, the 26th UN Climate Change Conference (COP26), and the European Union (EU) Green Deal to make clear the connections between sustainability and engineering. This section relies heavily on an extensive literature review conducted by project consortium partners. Next, using data that the project consortium collected through qualitative interviews with HEI stakeholders and industry representatives, the second section of the report highlights the state-of-the-art of sustainability in engineering higher education. This section allows us to understand where and how engineering programmes within HEIs have made inroads in embedding sustainability in their programmes, and map what programmes require to successfully embed sustainability within their programmes. We conclude with an outline of the most significant trends identified from the interviews, which will inform our approach in the following stages of the EESF project. Good Practice Cases interspersed throughout the report offer deeper understandings and examples for how the ideas presented in the report can be actualised in the classroom, in labs, or at institutions more globally.

1.1. The Sustainability Agenda

The term sustainability, and relatedly sustainable development, is one that has lacked consensus in both definition and usage (Klotz et al., 2014; Ruiz-Mallén & Heras, 2020). Three principal lines of thought have emerged around sustainability, the first a notion of a green economy supported by technological progress, the second pushing a shift in economic mindset away from the current growth model, and the third a risk managing and socio-technical solutions-oriented model (Adloff & Neckel, 2019; Ruiz-Mallén & Heras, 2020). Recent usages of the term sustainability have predominantly referenced climate change and other environmental initiatives (Heinberg, 2010). However, sustainability and environment are not synonymous with each other, but instead sustainability encompasses a broader set of goals for people, the planet, and the economy (Kulman & Farrington, 2010).

Major international institutions, including the OECD and EU, use the definition of sustainable development developed by the UN in the 1987 *Our Common Future* report (Brundtland Report), which defines sustainable development as "development that meets the needs of the present without compromising the ability of future generations to meet their own needs" (Brundtland Report, 1987). This definition, and the Brundtland Report more generally, became aligned with Elkington (1994)'s "triple bottom line" economic model, which proposed adding social and environmental responsibility to the conventional bottom line (Kulman & Farrington, 2010). It is this definition which has been used in each of the UN's development plans, including the 2030 Agenda for Sustainable Development (2030 Agenda) and its core of 17 Sustainable Development Goals (SDGs) (UN General Assembly, 2015).

These 17 SDGs are emblematic of the breadth with which sustainability reaches, encompassing social development, economic development, environmental sustainability, and peace and security (de Jong & Vijge, 2021; UN System Task Team, 2012). The SDGs, along with their 169 sub targets, set a global framework that spans numerous societal challenges with the aim of progressing humanity towards sustainable development (Adams et al., 2020), in a seeming attempt at bridging the differences between the differing visions of sustainability under one programme.

Figure 1: *The Sustainable Development Goals*

Source: *Azote for Stockholm Resilience Centre, Stockholm University CC BY-ND 3.0*

This Discovery Report is also framed around two key intergovernmental initiatives on sustainability, the European Green Deal (EGD), and the 26th UN Climate Conference (COP26). The European Green Deal (EGD), which was unveiled in December 2019, is the EU's *policy* strategy that forms a key component for the EU to achieve the goals set out in the 2030 Agenda by protecting the bloc from environmental challenges in a just and inclusive manner (Fetting, 2020). The EGD is composed of broad policy goals aimed at the green transition in Europe, from climate-related ambitions to energy production, construction, economic considerations, and ecological preservation (European Commission, 2019). COP26, held in Glasgow in 2021, reaffirmed the goals set by the Paris Agreement to limiting temperature increases, as well as highlighting the urgency of needed actions, transitioning from fossil fuels, and financing the green transition. Perhaps of most relevance to this report were the agreements for the Paris rulebook, which operationalises the Paris Agreement, and the Enhanced Transparency Framework on timelines and formats for reporting on progress towards meeting the SDGs (United Nations, 2021).

These two initiatives highlight a peculiarity that exists within the global sustainable development agenda, that while these challenges certainly exist at a global scale, as seen through COP26, the solutions to sustainability challenges must come from the regional and local levels. The European Green Deal highlights the priorities for the EU level, notably environmental protection and green transition, but at the same time also emphasises that EU Member States and regions have different needs, and that policies need to be flexible in order to accommodate needs at a local level (European Commission, 2021). While solutions developed at the global and national levels are often generic, the solutions developed at the local level are more capable of reflecting local values, ambitions, and capacities, all of which will allow them to develop in an economically viable and culturally acceptable way (UNESCO, 2018).

Despite progress on achieving the SDGs and other goals outlined in the sustainability agendas mentioned above at the global and regional level, there is still significant work to be done in order to reach these goals. The United Nations (2023) reports that the planet is on track to miss achieving all 17 SDGs by 2030, with achievement significantly impacted by the COVID-19 pandemic. At the current pace, gender equality targets will take hundreds of years to accomplish, while equality within and between countries has regressed and conflict-related civilian deaths have exploded. Meanwhile, progress towards sustainable economic growth has slowed and hundreds of millions are still living in extreme poverty. For sustainability targets more directly related to engineering, billions remain without safe drinking water, manufacturing growth has slowed, and solutions for renewable energy solutions remain vastly underfunded (United Nations, 2023).

At the regional level, the European Green Deal has spawned new regulations including the EU Climate law, binding Member States to a 55% reduction in emissions by 2030 and climate neutrality by 2050; the Regulation on Deforestation-free Products, which guarantees that products sold in the EU do not contribute to deforestation; and the Nature Restoration Law tackling biodiversity losses (European Commission, 2024; European Parliament, 2022). Progress on the achievement of these goals is mixed, according to the first annual report by the European Environment Agency (EEA), which monitors progress towards realising the goals of the EGD by 2030 through 28 monitoring targets (EEA, 2023). While the EU has made promising progress towards achieving some of its EGD goals, particularly those aligning with the zero-pollution action plan, the EU is currently set to miss several of its 2030 targets. The EEA report (2023) underscores in particular shortcomings in reducing environmental and climate impact from production and consumption, with goals related to energy consumption, circular material use, and organic farming falling behind goals set for 2030.

In order to achieve the SDGs and targets established by the UN and EU, significant support from the engineering sector will be required, from the development of new technologies to the re-development of manufacturing capacities, economic gains, and lifestyle improvements. However, engineering receives very little attention in economic and social development contexts, with texts often only referring to technology transfer capacities (Trevelyan, 2019). This disconnect will need to be addressed to make real progress towards achieving sustainability-related goals set at the global, regional, national, and local levels.

1.2 Engineering and the Sustainability Agenda

A rising set of trends and global challenges faced by society today, including mass urbanisation, changing global economic powers, climate change, aging populations, technological innovations, and the rise of entrepreneurship, have driven recognition of the connection between engineering capacity and economic development (UNESCO, 2021). Engineering, despite not being directly linked to the three prongs of environment, economics, and society that compose sustainability, instead has indirect links to each of these aspects. The resources used in engineering and engineering's outputs drive much of the world's economic activity, using resources derived directly from the environment, to develop products and services which elevate living standards, support social stability, and promote cultural and social development (Rosen, 2012). For example, developments like synthetic fertilisers, refrigeration, and the internet have all led to increased food supplies, higher quality of life and differing forms of fairness to society (Crosthwaite, 2021). Each of the 17 SDGs will require engineering solutions in some fashion (UNESCO, 2021), with reports suggesting that over 81% of the SDG targets are influenced specifically by infrastructure projects which rely heavily on engineering (Hall et al. 2016; Mansell et al., 2020; Thacker & Hall 2019). Sustainable agendas are often focussed on technological changes altering the provision of goods and services, preventing pollution and decreasing energy usage through systems changes, and developing innovative socio-technical systems (Ashford, 2004). Using an SDG lens to view infrastructure investments, for example, can lead to significant progress towards achieving the SDGs (Mansell et al, 2020). SDGs will have a heavy reliance on scientific contributions at all levels of implementation for the SDGs, while equitable distribution of essential needs requires engineering solutions for transportation (Fu et al., 2019).

UNESCO (2021) furthers this by suggesting that science, technology, and engineering lie at the core of sustainable development by establishing factual bases, anticipating future challenges, and innovating solutions to sustainability challenges. Global challenges require engineering solutions for air quality, food security, clean water supplies, energy, and communication, in addition to mitigation efforts for natural disasters and climate change-induced environmental effects (UNESCO, 2021). These solutions include new technologies which can provide benefits globally and across sectors, such as low-cost and high-efficiency lighting systems, energy systems, and systems with reduced greenhouse gas emissions (Trevelyan, 2019). Developing digital technologies will also play a significant role in developing more sustainable means of living, for example by opening up access to different public services, reducing emissions, increase production, and improve the efficiency of resources (Schmidt-Traub et al., 2019).

A number of SDGs are significantly connected to engineering, including SDGs 6 (clean water & sanitation), 7 (affordable & sustainable energy), 9 (sustainable innovation & infrastructure), and 11 (sustainable cities) (Mansell et al., 2020). One framework for embedding sustainability in engineering education, the Engineering for One Planet (EOP) Framework[1], identifies SDG 12 (sustainable consumption and production patterns) as the "most highly relevant and influential to the field of engineering", while also recognising a connection between engineering and all 17 of the SDGs (The Lemelson Foundation, 2022, p. 7). Goal 12 was highlighted by the hundreds of experts consulted during the development of the EOP Framework as the most relevant goal due to engineering's deep connection with every decision related to responsible consumption and production (The Lemelson Foundation, 2022; United Nations, 2015).

With the emergence of the sustainability agenda as a major societal focus across the globe, and one that figures to remain as such for decades to come as global trends continue and challenges remain, the question then is how to ensure that we maximise the capacities of engineers to contribute to solving sustainability issues both in the short- and long-term. While established engineers have certainly made substantial progress, future engineers will be relied on even more for increasingly impactful technologies, processes, and solutions. In order for their outputs to make an impact on the expanding sustainability crises, engineers must emerge equipped with and knowledgeable of sustainability tools, concepts, and principles, while being able to apply this knowledge to their work. At the centre of ensuring that the next generation of engineers are ready to take on these responsibilities are higher education institutions (HEIs), who must train their engineering students to understand the sustainability-related challenges that face our society.

[1] https://engineeringforoneplanet.org/

02 Sustainability in Engineering Education

According to the UN, education will play a key role in the successful achievement of the SDGs by 2030, by allowing learners to acquire the necessary skills to promote sustainable development (United Nations, 2015). Despite the recognised importance of engineering to achieving the sustainability agenda, however, adoption of sustainability concepts in engineering higher education remains sporadic and unstandardised.

To address these challenges and develop the embeddedness of sustainability in engineering higher education, a fuller understanding of the current approaches to embedding sustainability in engineering programmes and courses, as well as the perspectives of industry and accrediting bodies is essential. In order to enlarge this understanding, EESF project partners conducted an extensive literature review and carried out 50 qualitative open-ended interviews with HEI leadership, engineering educators, and engineering industry stakeholders. Our research addressed not only the current state of affairs, but also collected information on how to improve the existing situation and best embed sustainability mindsets, skills, and competences into engineering education, as well as the challenges to doing so.

The following sections of this report will first present a more developed argument for embedding sustainability into engineering education, then detail our findings, and finally provide some conclusions and proposals that we have been able to draw from our research.

2.1 The Case for Embedding Sustainability in Engineering Education

Higher education institutions (HEIs), due to their preeminent position at the centre of societies as generators and diffusers of knowledge, have a significant role to play in the implementation of the Sustainable Development Goals (SDGs), and are identified by SDG target 4.3 as actors that will allow the achievement of all 17 SDGs (Torres, 2021). Beyond target 4.3, SDG 4 (Inclusive & Equitable Quality Education) as a whole with its 9 other targets emphasise the idea that education is crucial for aligning society and the SDGs, and explicitly call for the direct involvement of HEIs, or state the significance of learning and teaching within HEIs to achieving the goal (Leal Filho et al., 2019). For example, target 4.7 focuses on ensuring by 2023, “that all learners acquire the knowledge and skills needed to promote sustainable development, including, among others, through education for sustainable development…” (United Nations, 2015).

While HEIs’ second and third missions of research and engagement with society, respectively, support this knowledge and skills acquisition, at the very foundation of an HEIs’ contributions is their first mission: teaching. Through the education of students, HEIs can not only develop the sustainability-related competences of the decision- and change-makers of tomorrow, but also allow them to reflect on and apply their individual values in their future careers (Weiss et al., 2021). Sustainability education emanating from HEIs must prepare students to live sustainably in global contexts, not only from within their discipline of study but also at the level of citizens who will both have impact on and be impacted by the planet (Leal Filho et al., 2019).

As established throughout Section 1, engineers will play a critical role in achieving the Sustainable Development Goals (SDGs) by helping drive innovation and technological advancement (Engineers Ireland, 2021). With strong problem-solving, design, and development abilities, engineers are well-placed to progress the sustainability agenda and have an overall positive impact on the planet and societies globally. Because of this, engineering faculties in HEIs in Europe and beyond are facing increasing pressure to integrate sustainability and the SDGs in their programmes in order to produce engineers prepared to address the global challenges outlined in sustainability agendas (Beagon et al., 2022; Quelhas et al., 2019).

This pressure is not coming from government sustainability agendas alone. The need for engineering students to emerge from their education with strong sustainability competences is evident in the labour market, with employers seeking workers who can understand and integrate sustainability and the SDGs in their work, engineering associations and other professional bodies seeking services to upskill existing engineers, and students growing desires to have sustainability-related careers. Despite the efforts of engineering programmes and HEIs more generally, however, a number of gaps remain when it comes to embedding engineering education in sustainability.

Often when faced with the opportunity, faculty members are not motivated to engage with sustainability-related challenges (Leal Filho et al., 2018). At the same time, financial restraints and other resource insufficiencies hinder university capacities to provide training to educators, and block them from embedding the SDGs in academic materials (Leal Filho et al., 2018; Leifler & Dahlin, 2020). Finally, the SDGs are inherently complex challenges that transcend traditional borders and informational siloes, necessitating a multidisciplinary approach and the integration of sustainability across disciplines (Körfgen et al., 2019; Serafini et al., 2022). As a result, forming appropriate assessment methods for these trans-disciplinary ideas is challenging in a field where traditional approaches focus on narrow and well-defined outcomes (Beagon et al., 2022). These challenges have resulted in only a small portion of engineering students receiving the education they need to tackle great sustainability challenges.

The gaps demonstrated in academic literature have been complemented by data collected during our interviews with industry and HEI stakeholders. Although there are some engineering students who emerge from their programmes with both the technical and transversal competences required for professional success, this is often not the case. More broadly than this, however, there is a lack of awareness about the wider environmental and societal implications of engineering. For example, Engineers Ireland-hosted focus groups revealed that students had no knowledge of 5 of the 17 SDGs, particularly on SDG 7 Affordable and Clean Energy and SDG 9 Industry, Innovation and Infrastructure which have particularly strong overlaps with engineering. This is all despite the finding that while the specific percentage varies by institution, overall, most students in engineering programmes have a positive perception about the SDGs and the broader sustainability agenda. Even students who are engaged and knowledgeable, however, were still found to lack the ability to concretely apply their skills and knowledge in practical settings.

Where students are well-trained and made impressions on employers, according to our interviewees, is through their technical skills, either general engineering competences or those specific to their discipline. However, recent graduates were noted as becoming too fixed, in some form, in the siloed nature of engineering education, often unaware of the links between different subdisciplines of engineering, other fields of study, and/or to external concepts such as ethics and sustainability. Due to this, graduates are emerging from their programmes lacking critical awareness of concepts and approaches such as systems thinking, as well as transversal inter-, multi- and transdisciplinary thinking skills that are crucial for the ability to craft a sustainability-oriented career path. The lack of this broader awareness and these transversal skills, in turn, has been found to have an impact on the level of some technical skills desired by employers, such as those related to renewable technologies.

Good Practise: Bringing Sustainability into Engineering Development Processes

A key aspect of sustainability in engineering lies in integrating sustainability principles directly into technology and product development processes. Engineers equipped with knowledge of life cycle analysis, emissions classifications, and sustainable design are invaluable to companies aiming to meet sustainability objectives. These professionals ensure that sustainability is embedded in every stage of a product's life cycle, from design to disposal, reducing the overall environmental impact of engineering practises.

The role of engineers in advancing sustainability is evident in how companies like Daikin AC (Spain) emphasise the need for technical knowledge on renewable energy and material life cycle management for meeting national and European regulatory requirements. At Wind Energy Ireland (WEI), sustainability has shifted from a secondary consideration to a central focus, particularly regarding long-term environmental impacts and site restoration. This shift has been driven by demands from investors and regulatory bodies for comprehensive sustainability plans, requiring engineers to be adaptive and responsive to these evolving requirements. Additionally, companies are increasingly offering in-house training and development programmes that focus on sustainability. HORSE Spain's endogenous approach to sustainability education provides continuous learning opportunities for existing engineers, ensuring that they remain up-to-date with sustainability trends and can integrate these practises into their ongoing work.

This combination of formal education and professional development allows engineers to stay aligned with industry objectives, ultimately advancing sustainability agendas. By following these examples and aligning coursework with industry objectives, engineering programmes in HEIs can enhance student professional outcomes by preparing them directly for what industry demands out of their workforce, and reduce the educative burden on industry; two outcomes which can also further achievement of sustainability objectives.

It is evident from academic literature that there is interest in, and steps being taken towards, the embedding of sustainability concepts into higher education in general, as well as engineering higher education more specifically. However, it is also demonstrated in the literature that the actions taken by HEIs are not standardised and have not been implemented in a way that consistently produces graduates capable of integrating immediately into the workforce. This lack of standardisation of the embeddedness of sustainability and the SDGs in higher education is also evident in the results of our interviews. Project partners conducted interviews in their four respective countries in Europe (France, Ireland, Portugal, and Spain), and there are wide variances between countries. As evidenced by our own investigation and by previous studies (Miñano et al., 2019), this has allowed a system to develop where sustainability has been integrated in isolated scenarios based on the motivations of faculty members, and therefore led to skills and knowledge gaps in graduating engineering students. The manner in which HEIs represented in our interviews have integrated sustainability competences in engineering education will be further explored in the next section.

2.2. The Current State of Embeddedness in Engineering Education

The previous sections of this report aimed primarily at establishing the necessity of embedding sustainability into engineering education. Academic literature has demonstrated that educators, students, industry, and other societal stakeholders such as government, employers, and local community members, all have a vested interest, for differing reasons, in having engineering higher education take steps towards integrating sustainability in their programmes and coursework.

With this in mind, the research conducted by the Engineering Education for a Sustainable Future project consortium's partners began with an investigation into the extent to which sustainability is currently embedded in engineering programmes in HEIs. In doing this, we are able to understand the existing practices and methodologies in place in order to highlight good practices as well as the gaps in current approaches to embedding sustainability into engineering education. This section will elaborate the state-of-the-art of embeddedness in engineering education, focussing on current approaches, activities, inputs and barriers to integration, as well as the sustainability-related skills HEIs are currently teaching students.

| State of Embeddedness

Within the HEIs included in our research, institutional, departmental, and programme level integration of sustainability varies significantly. In some institutions, such as Atlantic Technological University (ATU) in Ireland, faculty members have reported that while sustainability is integrated into their modules, this integration is not intentional or systematic across all courses. This is similar to the case at Université d'Aix Marseille, where despite having several programmes dedicated to sustainability-related topics including renewable energy, the wider sustainability agenda is not explicitly addressed in an intentional manner.

In contrast, some faculty members at HEIs, such as the Institut Mines-Télécom Business School (IMTBS), also in France, indicate a more systemic incorporation of sustainability. Institut Politecnico Porto (P. Porto), similarly to IMT-BS, has a wide integration of the SDGs across the institution. In contrast, however, some SDGs receive more attention and focus within the curricula with certain SDGs seemingly having a higher importance

Good Practise Case: Application-Based and Community-Oriented Approaches to Promote Sustainability

A pattern emerging from several from both HEIs and engineering associations is the emphasis on real-world experience and practical applications as an effective way to embed sustainability into engineering education. At ATU, for example, sustainability is taught through practical projects like the 'Design for X' challenge, which focusses on the circular economy and sustainable product design. By engaging students in real-world challenges, such as energy conservation, students gain insight into applying sustainability principles within engineering contexts. From an industry standpoint, WEI highlights the value of internships, co-ops, and hands-on projects. These opportunities provide students with the chance to tackle sustainability challenges and observe the direct impact of their efforts on real-world issues. The experiences enhance their understanding of sustainable practises and prepare them for the complexities of sustainability in the engineering field.

Service learning and community engagement represent another effective practical approach to embedding sustainability in education, as emphasised by both engineering associations like the Student Platform for Engineering Education Development (SPEED) and HEIs including P. Porto. One interviewee from SPEED emphasised community and service-learning projects, where students solve real-world problems using engineering principles. These projects often align with the Sustainable Development Goals (SDGs), engaging students in activities like developing IoT devices or building mechanical systems that solve community issues. This community-centric approach is also practised by the Université de Technologie de Troyes (UTT) in France, which implements hands-on projects that address actual sustainability challenges posed by local city halls, associations, or companies. This approach shifts the focus from traditional exams to real-world impact while driving student motivation by showcasing the practical applications of their knowledge. Students working on these projects encounter challenges integrating multiple fields of study including environmental sciences, engineering, and ethics.

P. Porto similarly emphasises service-oriented learning, using practical projects such as waste recovery and sustainable product design to foster sustainability awareness. Research groups like CIETI and GRAQ at P. Porto further enhance students' involvement in sustainability efforts, helping them develop both technical and non-technical skills necessary for sustainable development.

than others. At Universidad Politecnica de Madrid (UPM), the institution actively embeds sustainability across student activities, teaching, and environmental enhancements in various facilities. UPM aims for a comprehensive integration of sustainability, with a particular focus on education, research and the school itself.

Somewhere in the middle of these two ends are examples such as Université de Technologie de Troyes (UTT) in France, who have several masters programmes and a number of faculty dedicated to sustainable development but made little reference to any institution-wide implementation of sustainability efforts.

Engineering associations highlighted a broader view of engineering programmes, noting the need for more consistent and widespread integration of the SDGs and the sustainability agenda across all engineering disciplines. Industry representatives generally expressed that current efforts to embed sustainability in engineering programmes are often insufficient, stressing the importance of embedding the SDGs in educational outcomes in alignment with industry needs.

Good Practise Case: Competency-based Approaches to Promote Holistic Education

Another good practise pattern identified across institutions like École des Ponts-ParisTech, IMT, and P. Porto is the use of competency-based frameworks to embed sustainability into engineering education. École des Ponts-ParisTech incorporates competences aligned with UNESCO's SDG competency framework and the Bologna Process, ensuring that students acquire skills necessary to address sustainability challenges in a multidisciplinary context.

IMT takes a similar approach by designing a competency framework that integrates ecological awareness into engineering education. This competency-based approach transcends traditional technical disciplines, promoting a holistic view of sustainability that encompasses ecological, social, and economic dimensions. In both institutions, sustainability is woven into the curriculum, not as an isolated subject but as a set of competences that inform various engineering disciplines.

This integration of sustainability into core competences allows institutions to train engineers who are well-equipped to address sustainability challenges holistically. By embedding ecological awareness and sustainable practises into their programmes, these institutions enable students to view sustainability as an integral part of their professional roles, not merely an additional subject. Further, the use of existing frameworks provides the programmes and HEIs as a whole a framework against which to build out their pedagogies and measure student successes.

Approaches

There are also a wide variety of approaches to embedding sustainability, with schools and programmes varying in the depth of integration and the methodologies used to do so. Several programmes were detailed as being dedicated to sustainable engineering, with courses and modules throughout the programme linking sustainable development practices to engineering competences. These programmes often used existing frameworks, for example the UNESCO Competency Framework is used at the École des Ponts ParisTech in France, as guidelines for embedding sustainability. Others took a less intentional approach, either giving students the option to take courses on sustainability throughout their programmes or including sustainability as part of first year module series.

There are also a range of differences in the way sustainability is taught in the classroom, though many of our interviewees across countries and institutions mentioned employing practical assignments as well as challenge- and project-based learning and exercises. While some programmes embed sustainability competences across student courseloads, others prioritise thematic and interdisciplinary courses, on environmental engineering for example, or including sustainability as a requirement in capstone projects. Many faculty also leverage their personal connections to invite guest lecturers, either academic specialists or industry members, or to organise on-site visits to companies working on sustainable engineering solutions.

Externally from HEIs, engineering associations advocated for more standardised approaches and good practices which could be adopted across different institutions to ensure more consistency in sustainability education, while industry representatives favoured approaches that provide students with practical real-world experiences, including internships and collaborative projects with companies that focus on sustainability.

| Activities

A number of specific activities taken at the course, programme, departmental, and institutional levels to embed sustainability into engineering education were cited by interviewees.

At the departmental level for instance, the UPM in Spain has incorporated sustainability into the grading system by ensuring that it accounts for at least 0.25% of a student's grade in the master's final project. This initiative highlights the importance of sustainability by directly linking it to academic performance and student assessment. Departments at interviewee institutions are also organising sustainability-themed seminars, creating specialised research groups, and integrating the SDGs into their departmental strategic planning.

At the institutional level, activities included the implementation of sustainability audits, which assess the environmental impact of campus operations and identify areas for improvement. These audits help institutions track their progress towards sustainability goals and make data-driven decisions to enhance their environmental performance. In addition to this, interviewees gave examples of campus greening projects, and sustainability committees. UPM has stood out as an exemplar in institution-level activities for embedding sustainability, making significant investments towards ecological transition and allocating funds to improve energy efficiency and promote responsible consumption on campus.

Other institutions have either developed or participate in different working groups related to sustainability. The École des Mines-Saint-Étienne for example has a group called Sustainable Development and Social Responsibility (DDRSE), which works on sustainability in research, teaching and administration with a focus on decarbonisation, mobility and energy sobriety. P. Porto similarly performs activities as an institution to further sustainability, including participation in the Portuguese Pact for Plastics and the Porto Climate Pact, integrating into sustainable campus networks and within the Sustainable Development Solutions Network, and the development of the P. Porto Commission for Sustainable Development to manage sustainability on campus.

| Challenges & Barriers to Embedding Sustainability in Engineering Education

As reflected generally by faculty, and in particular those at ATU and within the Institut Mines-Télécom (IMT) group in France, engineering programmes lack the institutional support and resources needed to embed sustainability, while institutions remain more broadly resistant, either structurally or on an individual level, to changes in curricula. Even where institutions are embedding sustainability, they may not leverage all of the resources they have access to, in particular industry and other experts that are either on-site or which have direct connections with academics involved in these programmes.

One of the greatest challenges, in particular in France across several institutions, is that engineering faculty often do not feel comfortable enough teaching about sustainability as consider themselves as lacking the expertise to teach it. One teacher-researcher at the Université d'Aix Marseille noted that in their experience, a more holistic approach to engineering requires true expertise on a topic to avoid turning lectures into subjective discussions. Therefore, teaching sustainability without having a truly objective mindset would be ineffective and would prevent students from forming their own opinions on the subject matter. This is especially true for the topics that are at the centre of public debate and discussion and where differentiating between opinion and fact is challenging. At the centre of this challenge is a feeling of lacking the legitimacy to discuss an issue because the faculty are not an expert on it, causing discomfort when asked to integrate the topics directly into course material.

On the other hand, engineering associations highlighted systemic challenges to embedding, including the need for policy changes and better support structures to facilitate the integration of sustainability in engineering programmes. Misalignments between the results of educational practices and the competences required of graduates entering the job market emerged as the greatest challenge for industry, who stressed the need for more industry-aligned approaches to curriculum development and teaching.

Current Skills Development

As emphasised throughout Section 1, engineers are powerful agents for advancing the sustainability agenda due to their unique skillsets and knowledge as well as the influence that engineering employs over everyday society. Increasingly, industry has valued sustainability skills for engineering positions which are considered essential for project planning and complying with an ever-expanding set of environmental regulations. Higher education engineering programmes already focussing on sustainability or sustainability-related topics emphasise a number of skills which are necessary for engineering students to have successful sustainability-oriented careers, a set which we term “sustainability skills”. These skills can be further broken down into two categories, the technical skills necessary for engineering and its specific branches such as models or technical tools, and the transversal skills including social or interpersonal skills and attitudes.

Technical Skills

Technical skills can be broadly organised into two categories, the technical skills which are taught specifically within engineering programmes and the project management skills which are not unique to engineering but are inherently technical. At the core of the technical skills, as emphasised by several interviewees, are the foundational scientific skills which form the base of comprehension of any subsequent education.

Across the board, students acquire the technical skills they need to integrate into their chosen branch of engineering, and any further specialisations they may pursue. In addition, skills such as digital and mathematical modelling, data analysis and systematic, life-cycle analysis, and various simulation tools are taught to give students a foundation in the engineering sciences. Many of these tools and skills, such as digital modelling and data analysis, can help students visualise or evaluate the different sustainability options available to them in their coursework and to understand the environmental impact of different engineering solutions.

Beyond the technical skills which can be applied broadly to engineering careers, a number of skills currently taught in engineering programmes can be applied specifically to sustainability-oriented programmes and career pathways. Enhancing student understanding of sustainability principles and of the SDGs did vary, with some educators emphasising an understanding of the basics, while others mentioned students receiving a comprehensive understanding of sustainability principles. Students were taught, to varying extents, to understand the environmental impact of engineering projects and the steps that they can take to reduce projects’ environmental impacts. In many programmes, whether directly linked to sustainability or not, educators highlighted that students emerged with knowledge on renewable technologies, such as energy systems and sustainable materials, in addition to being able to perform energy efficiency calculations, understand renewable energy systems, and apply sustainability tools such as Life Cycle Assessments (LCA) and the Global Reporting Initiative (GRI)[2].

Good Practise Case: Digital tools for sustainability

Some essential technical skills highlighted across institutions were proficiency in simulation tools and the use of digital technologies for sustainability assessments. HEIs like ATU, private sector organisations like SIKA-Spain, and engineering associations such as the International Association for Continuing Engineering Development (IACED) emphasise the growing importance of digital tools in modern sustainable practises, whether for energy performance assessments, material science simulations, or renewable energy systems analysis.

Simulation tools allow students to model real-world scenarios, testing variables like energy consumption, material durability, and carbon emissions under different conditions. This ability is especially critical in construction and engineering projects, where accurate data can inform better design decisions. ATU's curriculum, for example, teaches students to conduct thermal bridge assessments and moisture risk analyses using specialised software. SIKA reinforces this by noting that students with proficiency in these digital tools are better equipped to perform life cycle analysis and eco-design once they begin their careers.

This trend is also reflected in programmes about renewable energy systems, where students at institutions like Institut Mines-Télécom - Mines Albi (IMT-Mines Albi) use simulation tools to evaluate energy conversion processes and assess environmental impacts. These digital skills not only enhance students' technical abilities but also improve their problem-solving capabilities in complex, multidisciplinary sustainability projects.

By integrating simulation tools into their curricula, institutions are ensuring that students can bridge the gap between theory and practise. This proficiency allows future professionals to create more accurate sustainability assessments and solutions, ultimately leading to better resource management and optimised system designs.

One example that stands out is a programme at ATU which focuses on teaching both technical and analytical skills necessary for sustainable construction. The practical skills emphasised in the programme include energy performance assessments, moisture risk analysis, and carbon counting. These skills prepare students for industry demands by

[2] https://www.globalreporting.org/

ensuring that they effectively engage in modern sustainable construction and retrofitting projects.

Other programmes, such as one at P. Porto, emphasise technical skills in a specific sector to understand the process in which sustainability is being implemented in that sector. Managing agricultural waste for example requires technical knowledge about agricultural production in order to find sustainable solutions for waste disposal. Other programmes teach competences on environmental impact in programmes on energy conversion, building regulations and materials choice in construction-focussed programmes, and life cycle analysis across programmes of all types. Owing to the multidisciplinary nature of sustainable engineering, several socio-technical skills were highlighted in our interviews. These skills principally highlighted legal and regulatory issues, which students are taught to understand more broadly on environmental regulations and the current legal and regulatory frameworks for engineering projects. Some programmes ensured students were equipped to understand the regulations in their subfield such as building regulations.

Good Practise Case: Tailoring Communication for Diverse Audiences in Sustainability Projects

Effective communication is essential in conveying sustainability efforts, especially when dealing with diverse audiences, as demonstrated in practises industry members Wind Energy Ireland (WEI), HEIs like P. Porto, and engineering associations like SPEED. The ability to tailor messages according to the audience's background is a crucial transversal skill for professionals engaged in sustainability-related work. For instance, engineers at WEI need to explain complex technical data to both their technical peers and non-technical stakeholders. When speaking with technical peers, the focus is on precision and technical accuracy, ensuring that everyone involved understands the complexities of methodologies and solutions. However, when communicating with executives, engineers translate these technical details into business language, emphasising the strategic advantages and financial benefits of sustainability.

Similarly, P. Porto's focus on the broader societal communication of sustainability highlights the importance of framing corporate sustainability narratives in a way that resonates with different audiences. This is often achieved by avoiding jargon that might not translate well across languages or cultures and focussing on terms that better resonate with the audience. For example, instead of using the term "sustainability," which can evoke pre-conceived biases, the discussion is reframed in terms of practical impacts and societal benefits of the practise of sustainability. The goal is to avoid potential misunderstandings and to ensure that the key concepts resonate, regardless of the specific language used. Similarly, WEI and SPEED's mentalities towards communicating with non-technical audiences involves simplifying technical terms and focussing on practical outcomes rather than the technical details themselves. This not only enhances understanding but ensures that the audience appreciates the value of sustainability efforts within the context of their own priorities.

Through these approaches, professionals in sustainability-focussed roles can align their communication strategies effectively with their audience, promoting clarity, engagement, and the successful implementation of sustainability initiatives.

Project Management for Engineering

The project management skills taught in sustainable engineering programmes focussed on higher level objectives and long-term thinking. These include resilient strategy development, having knowledge of planning systems, and on environmental impact throughout technology lifecycles. Assessments for aspects of projects are also taught, including lifecycle costs of building materials, performance assessments of technologies, environmental impact assessments, and carbon assessments.

This range of skills taught across several institutions, from materials selection to renewable energy and engineering management, underlines the importance of equipping students with practical skills relevant to sustainable engineering practices. While technical skills for sustainability are being embedded in engineering curricula, there is room for improvement. Notably, there is room to more systematically embed many of these competences across engineering programmes, especially the skills that are targeted towards sustainability (see Section 4: Conclusion for more on this).

Non-technical/transversal skills

While the previously discussed technical skills are certainly critical requirements for sustainability-oriented careers in engineering, engineering programmes are also prioritising the teaching of non-technical and transversal skills. Transversal skills are oriented towards more human skills and human sciences with concepts relating to the sociology of organisations, change management theories, crisis, transition, and interpersonal relations. Transversal skills also focus on raising awareness about the societal impact of engineering work, encouraging students to consider sustainability in all aspects of their coursework as well as professional projects. These skills enable students to envision sustainable solutions and understand their broader impact. Emphasising these competences ensures that students are not only knowledgeable about sustainability issues but also capable of devising and implementing practical solutions. Currently within engineering programmes, the most commonly emphasised skills are critical thinking, creativity, problem solving, and innovativeness. During our research, interviewees generally broke transversal skills down into two categories, soft skills and attitudes.

Soft Skills

Social and human skills are critical for engineering graduates, particularly for engaging in work on interdisciplinary and collaborative engineering projects. Programmes and courses emphasise collaboration, teamwork, communication, and leadership skills. The need for these skillsets emerged out of a need to engage better with the public and design solutions that are human-centric and consider human interactions with sustainability as well as with technology.

The need to connect engineering solutions with external stakeholders, and society as a whole, requires a particular skillset. At the core of this set of competences is the ability to understand broader societal needs, the implications of technological development on society, and to contextualise sustainability. Engineers are further educated on how to navigate the complexities of these scenarios. Leadership and advocacy skills are also taught as critical for promoting sustainability within engineering circles, while communicating sustainability without using jargon provides critical communication tool for reaching external audiences.

Understanding and utilising skills related to the social elements supplement and support systematic analyses, a process which has emerged as a core part of sustainability engineering. Understanding the systems that surround engineering solutions to sustainability, including the solutions themselves, teaches students to understand sustainability through its social, environmental and economic components in an integrated manner. Alongside this, foresight is emphasised to give students the ability to think about the long-term and develop strategy resilience. At the core of this is the consideration of sustainability in aspects of engineering projects, keeping in mind to design projects with such notions as the environment in mind. Others noted more organisational skills emphasised in their courses, such as the sociology or organisations, change management for crisis and transition, and management of material flows in companies.

Good Practice Case: Building Transversal Skills through Engagement Beyond the Classroom

Other approaches to fostering transversal skills were highlighted in institutions like École des Ponts ParisTech and P. Porto. These programmes recognise the value of learning beyond the classroom and emphasise the importance of continuous personal and professional development.

At École des Ponts ParisTech, students are paired with experienced professionals who offer guidance and insight into sustainability practises within the engineering industry. This mentorship provides students with first-hand insights of how sustainability is integrated into real-world projects and helps students to develop the critical thinking skills needed to lead these initiatives themselves.

Similarly, P. Porto promotes a culture of lifelong learning, encouraging engineers to continually update their skills and knowledge. In an ever-evolving field like sustainability, this approach ensures that graduates remain adaptable and well-informed, positioning them as leaders in their respective industries. By maintaining and facilitating strong industry connections through networking events and professional development programmes, students gain access to a broader pool of knowledge and expertise.

These institutions illustrate that mentorship, networking, and a commitment to continuous learning provide the necessary support and growth opportunities for students to thrive in a dynamic, interconnected world.

Finally, because of the multi-disciplinary, multi-dimensional, and collaborative nature of developing solutions to sustainability challenges, building interpersonal communication skills is stressed in the classroom. These communication skills are built in the classroom often through problem- and team-based learning projects which force students to work collaboratively with their peers and with external stakeholders.

Attitudes & Mindsets

Though also a required and emerging skillset, students are also taught at some institutions to have a mindset geared towards systemic thinking. This mindset has developed in response to concern that students focus too narrowly on the technical side and must move beyond this to develop a holistic vision of sustainability. This directly connects with many of the other attitudes which are taught to students, including understanding the social, economic, and environmental implications of sustainability solutions; maintaining global awareness; and understanding the effects of geopolitics on sustainability. Maintaining these mindsets allows students to more strongly focus on the needs of society for a sustainable future, as well as the impacts of engineering, instead of solely focussing on product development and technology.

Mindsets may also be specific to certain disciplines such as sustainable waste management, as described by one interviewee at P. Porto. Having an attitude of “do not waste, be aware of the consumables you use, be aware of how to separate waste, do not waste excessive water when washing material” can help students build sustainability principles into their lives and work.

Inputs

The inputs needed for embedding sustainability can be divided into four categories, institutional inputs, departmental inputs, academic or professional inputs, and external inputs. Across the board, the most commonly-referred to inputs by interviewees were financial resources and funding opportunities at the institutional level. Other institutional-level inputs include the provisioning of infrastructure and human resources, time, and support from institutional leaders.

Institutional

One interviewee from ATU mentioned that ATU supports sustainability through continuing professional development (CPD) offerings and funding for projects such as the climate action leadership training program in an ad hoc fashion. Other institutions take more direct approaches, through the direct provision of infrastructure, financial and human resources, and providing support to teacher-researchers who are less comfortable with sustainability topics. Throughout our interviews P. Porto emerged as a leader in these types of initiatives, having created internal entities to count and manage waste, provide collection points for glass and paper, and organise a sustainability committee which provides political and financial support towards sustainability initiatives on campus. In recognition of these, they were recognised as an exemplar for sustainability initiatives during the 75th anniversary of the UN. Universidad UPM also emerged as a leader on this front by creating a sustainability delegate on the management team to coordinate and advocate for sustainability-related activities among faculty and students.

The structure of academic programmes at the institutional level may also play a facilitating role in embedding sustainability. France, for example, has engineering schools which offer a three-year program, rather than separate master's and PhD programs allowing for a more integrated and applied learning experience. The programmes are not limited to strictly technical teachings, often including economics and social sciences to engineering programmes and facilitating the embedding of sustainability. Where the institutional structures are not conducive already to embedding sustainability, support from leadership has been essential for allowing faculty efforts to develop into reality.

Good Practice Case: Cross-Functional Collaboration & Stakeholder Engagement

Collaboration across disciplines and with external stakeholders is an essential practice in achieving sustainability goals. As observed at both P. Porto and Wind Energy Ireland (WEI), sustainability initiatives demand engagement with a wide range of partners, from internal team members to external stakeholders such as policymakers and community members. The ability to communicate effectively within a team is fundamental to this collaboration. At P. Porto, there is a focus on teaching students to foster a collaborative attitude where colleagues exchange ideas and perspectives, recognising that no individual can master all aspects of sustainability independently.

At WEI, engineers collaborate with both on-site personnel and external stakeholders to ensure that sustainability practices are understood and implemented effectively. Clear, practical communication is key to ensuring on-site workers follow sustainability guidelines in their daily operations, while dialogue with community members and policymakers needs to emphasise how sustainability initiatives will directly benefit them. Engineers, in this case, act as intermediaries, bridging the gap between technical solutions and public concerns.

Both institutions demonstrate that achieving sustainability goals is not just a matter of internal teamwork but also of broader engagement with external stakeholders. Fostering trust, understanding, and cooperation through effective communication enables all parties to work toward a shared vision of sustainability.

Departmental

Support and leadership were also considered crucial inputs at the departmental level, in particular for continuing professional development on the integration of sustainability. Beyond this, leadership from teacher-researchers is imperative for the development of new courses, modules and programmes that are dedicated to or involve sustainability in some way. This type of leadership often works hand-in-hand with institutional leaders, who give the teacher-researchers the legitimacy to pursue these topics. Other inputs mentioned were more direct involvement from departments, including developing or hosting internal training for faculty and staff on sustainability, and participation in external working groups and conferences on sustainability to further familiarity with sustainability.

Academic/Professional

As a baseline to incorporate sustainability into engineering programmes, the faculty teaching within the courses need a high level of understanding of sustainability. The quality of what is taught therefore depends heavily on the teachers and their training. One interviewee from France noted that there is a very visible different between the educators who have training or specialisations in sustainability versus those who come from other disciplines to teach on sustainability. Continuous professional development is often the most available option for academics to develop the competences and knowledge necessary to teach about sustainability and to maintain knowledge and integrate the latest knowledge in sustainability practices into curricula. These can take the form of optional and mandatory events, modules, trainings, and certifications, providing knowledge and skills to the faculty who can then incorporate their skills into their courses. This was particularly evident at ATU, where faculty and staff may receive trainings on sustainable topics and utilise relevant software and equipment to enhance their own teaching effectiveness. The result of both faculty education and continuous professional development is a conviction within teacher-researchers to be able to implement sustainability on their own without reluctance.

Where faculty do not have the right competences, or feel unsure about teaching a subject, incorporating multidisciplinary lectures and project-based learning have contribute to embedding sustainability concepts in education, as well as expert-led lectures and targeted lessons to integrate the SDGs more effectively.

External

Outside of faculty and HEI management, student and industry demand for sustainability competences can impact their inclusion in engineering programmes. Student demands for sustainability-oriented educations were particularly impactful for driving embedding as they increasingly demand more education on renewable energy and sustainability. Industry links have played a similarly impactful role, providing practical experience through student-led projects, visits, and guest lectures. Academics can also benefit from these connections, with HEIs such as P. Porto developing projects in collaboration with government and institutional bodies as well as with industry to help disseminate information.

Relatedly, one valuable resource for IMT is the European Union's support through European alliances and university agencies. These alliances, such as the EULiST alliance (of which IMT is a member), encourage academic excellence while also connecting academia with society and industry with an aim of fostering impact beyond the walls of the university.

Accreditation bodies can mandate the inclusion of sustainability competences in programming, while programmes, institutions and even individuals can benefit from sustainability-related certifications. Regarding sustainability-related certifications, one very recent example indicated by an interviewee includes a Siemens micro-credential for sustainable engineering. These certifications and programmes allow students both during their trainings and careers to receive the expertise on sustainability they need external to traditional programme structures. Accreditation bodies such as The Accreditation Board for Engineering and Technology (ABET), the main engineering accreditation body in the United States, has also added student outcomes that broadly relate to sustainable development. Most importantly is ABET Student Outcome 2, which requires students to be able to develop solutions that consider broader social issues, including public health and safety in addition to global social, environmental, and economic factors (ABET, 2023). The executive director of ABET as well as other HEI leaders from the US and Europe who participated in a forum hosted by Engineering for One Planet, with which one interviewee was connected, detailed that sustainability needs to be mandated by accreditation bodies, a move that they were certain would speed up the embedding process. Inclusion in accreditation processes would also make it easier for teacher-researchers to understand and develop sustainability-oriented programmes by providing sustainability toolkits and mappings.

Some final external inputs indicated by interviewees include participation in external working groups and conferences, inclusion of external software, integration of community-based projects, and external programmatic reviews of engineering programmes. In particular, programmatic reviews help ensure that programme outcomes align with different sustainability objectives.

03 Recommendations to Better Embed Sustainability into Engineering Education

Section 2 presented the need for a state-of-the-art of embedding sustainability competences in engineering higher education, demonstrating a range of rationales and methods for embedding sustainability. What the data from academic literature and our qualitative interviews revealed is that the embedding of sustainability competences into engineering education is something that has indeed begun to take hold in engineering higher education.

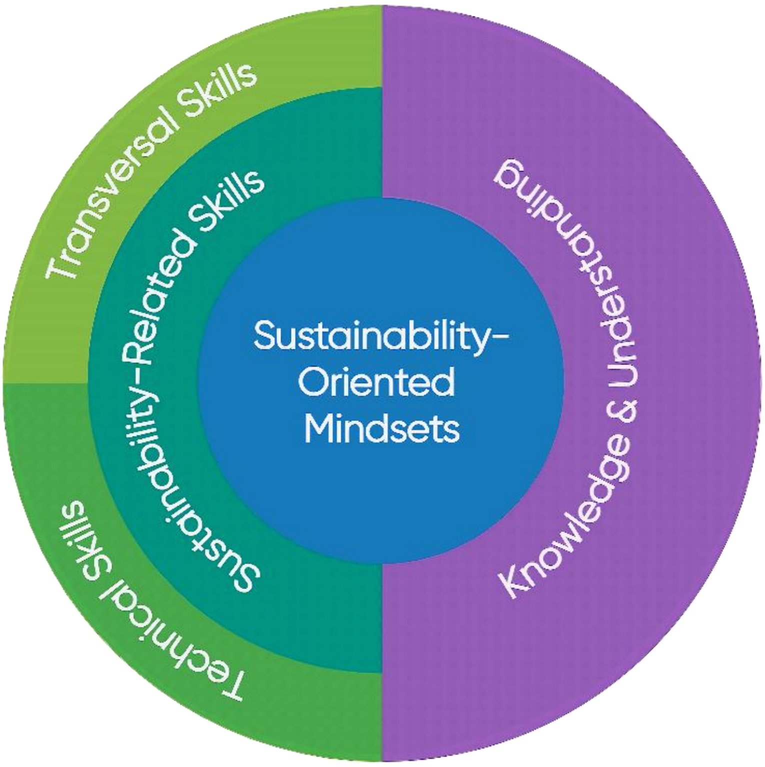
Despite this, there is no real standardised methodology or framework which has allowed engineering programmes to systematically embed sustainability into their pedagogies. This has led to significantly varied content, foci, and pedagogical approaches in engineering programmes, even within the same countries, regions, and in some case, schools. Despite the diversity of approaches and methodologies presented by the data, several broad themes have emerged throughout the interviews which will have strong implications for the EESF project. These themes have informed a set of recommendations which will be detailed further in this section.

Figure 2: The Engineering for One Planet Framework

Source: The Lemelson Foundation, 2022

The recommendations that we provide in this section have been heavily influenced by the Engineering for One Planet (EOP) Framework (seen above in Figure 2), developed by the Lemelson Foundation, after being informed of its relevance by one of our interviewees. The EOP Framework serves as the foundation against which we base our recommendations, adapting it to reflect the research carried out by the Engineering Education for a Sustainable Future (EESF) project consortium. Our recommendations rest around a core of Sustainability-Oriented Mindsets which is surrounded by Sustainability-Related Skills (further divided into technical & leadership skills), and Knowledge and Understanding. While these three sections are distinct, they are interconnected and dependent on each other, with progress in one area also supporting progress in others. Globally, we recommend the incorporation of these three categories into existing engineering pedagogies to support the embedding of sustainability into engineering programmes. The following sections will discuss these categories in more detail, followed by some additional themes discovered throughout our interviews which will also be helpful to consider for engineering courses.

Figure 3: A Simplified Framework for Embedding Sustainability into Engineering Education



Source: Authors' Visualisation

3.1. Recommendation 1: Develop Sustainability-Oriented Mindsets in Students

Certain mindsets, which constitute a set of beliefs and attitudes held by an individual, were highlighted by interviewees as crucial when it comes to embedding sustainability in engineering education and practice. These mindsets included in particular systems thinking and ethical decision-making which were discussed repeatedly during the interviews. The importance of an multidisciplinary mindset was also frequently mentioned, in most cases as having a direct impact, but also an indirect one, as this mindset is a requisite for understanding and awareness of the various interconnections between engineering and society. Implementing trainings into curricula is critical to developing these mindsets in students.

Multidisciplinarity

Multidisciplinarity is a critical theme emerging from both academic literature and the interview data collected. Sustainability challenges are inherently complex, spanning social, economic, and environmental dimensions, and as a result, require integration across disciplines to be effectively addressed (Quelhas et al., 2019). This complexity demands engineers who are not only technically proficient but also capable of navigating and synthesizing knowledge from diverse fields, allowing them to develop solutions that consider multiple interrelated factors (Van den Beemt et al., 2020).

Sustainability issues do not exist in isolation; they are system-wide and interconnected. Therefore, future engineers must be trained to understand not only the technical aspects of their field but also the broader contexts in which they operate. Multidisciplinarity plays a crucial role in achieving this, providing students with the tools to consider and integrate various perspectives into their engineering practice. This ability is particularly important in sustainability-oriented engineering, where solutions need to account for social equity, economic feasibility, and environmental protection simultaneously.

By promoting multidisciplinarity, engineering programs can foster the critical thinking and systems-oriented approaches that are essential for addressing these multifaceted challenges. Our interviews revealed a strong consensus among educators that a humanistic and multidisciplinary approach helps students develop the capacity for innovation, creativity, and social awareness. Through multidisciplinary learning, students move beyond narrow, discipline-specific thinking and are better equipped to create comprehensive, integrated solutions to sustainability problems.

One French educator emphasised the importance of teaching students to approach problems from multiple dimensions simultaneously. By understanding how different aspects of a problem interact—whether social, economic, or technical—students are better able to devise coherent solutions that function across these domains. This integrated approach is essential for addressing the global, complex challenges posed by sustainability.

Multidisciplinarity equips students not only with technical competences but also with non-technical ones such as critical thinking, systems thinking, and the ability to consider the broader impacts of engineering solutions. These competences help future engineers devise solutions that are not only technically sound but also socially and environmentally sustainable.

Good Practice Case: Multidisciplinary Approaches to Sustainability in Engineering Programmes

Multidisciplinary approaches are essential in embedding sustainability within engineering programmes at European HEIs. For example, P. Porto's European Project Semester and Sustainable Energy Master's programme bring together students from diverse fields, encouraging them to tackle sustainability challenges from multiple perspectives. At UPM, multidisciplinary skills such as communication, mobility, and language proficiency are also incorporated, allowing students to engage with engineers, experts in other disciplines and civil society actors crucial to the effective implementation of sustainability-related projects.

At ATU, students work on specific sustainability challenges from the outset, acquiring both technical and transversal knowledge and skills as they progress. Engineering projects at ATU integrate the three pillars of sustainability—economic, social, and environmental—into the learning process, ensuring that students consider the broader impacts of their technical solutions. The emphasis on cross-disciplinary collaboration ensures that students' learning goes beyond mere technical expertise by allowing students to explore innovative and multidisciplinary solutions to real-world problems.

In France, at École des Ponts ParisTech, foresight education is embedded into the curriculum, encouraging students to develop long-term strategic thinking. This approach broadens their capacity to integrate stakeholders early in the decision-making process, ensuring that engineering solutions align with societal needs. Similarly, UTT emphasises the importance of understanding human behaviour and organisational sociology, particularly in crisis or transition situations, which adds another dimension to traditional technical training.

In these institutions, students are encouraged to address tangible engineering challenges but also consider non-tangible factors such as social equity and environmental justice. The collaborative nature of these projects also promotes innovative thinking, pushing students to consider sustainable design choices and strategies that challenge conventional methods. These experiences often lead students to seek further training in sustainability-related areas, thus broadening their capabilities and bridging the gap between theoretical knowledge and practical application.

Ethical Mindset

Embedding sustainability into engineering education should be approached in the same way as ethics in education since sustainability is in many ways a form of ethics. Where we see some of the greatest challenges today, with environmental degradation, sluggish economic development, and unfair social practices towards certain groups, there are opportunities for sustainable engineering to have a rectifying effect. Without an ethical mindset, many of these challenges would continue progressing without regard for the impact they have on the planet and on humanity. However, if engineers are trained to build ethics into all layers of their work from design to implementation, there will come an understanding of the value they can create in society. This stems from considering the most ethical solution to a certain challenge, developing a solution to a specific challenge creating unethical situations, or by lifting a community of people towards a better economic standing. Our interviewees have emphasised that ethics has generally been very successfully embedded into engineering education, following either one-off approaches or embedding ethics practices into each course. This approach further teaches the students to be inherently aware of the societal impact of their work.

Systems Thinking

Throughout our interviews, it became clear that at the core of embedding sustainability in engineering education is a systems thinking mindset. A systems thinking approach to engineering encourages students to think beyond the traditional boundaries of engineering to consider the plurality of dimensions in which engineering exists in an integrated manner. Because sustainability, and its inclusive subdomains, is complex and multidisciplinary, and often involves uncertain outcomes, engineers who are used to developing definitive solutions can face new challenges developing solutions to sustainability challenges. By teaching students to think beyond the silo of engineering, the solutions they develop can also become multi-dimensional and integrated, with the aim of ensuring that projects are coherent across disciplines. This understanding can take form in multiple ways, from understanding that technology and other engineering designs are in fact systems (The Lemelson Foundation, 2022), recognition of the social impacts of climate change, to the economic challenges facing least-developed nations.

Having a systemic vision and understanding broader systems and their interconnections is a valuable mindset which allows students to maintain a higher perspective and take a step back. Though some academics mentioned the challenge of building the education of this mindset into curricula, it can be accomplished through the utilisation of projects that apply skills learned across different modules or parts of a course. This helps develop a broader vision without locking down from the start, but rather encouraging reflection on these topics. Allowing students to develop these competences ensures that they are not only knowledgeable about sustainability issues, but also that they are able to develop and implement solutions which consider a problem from a technical standpoint as well as the social, environmental, and social angles. Such projects also encourage a collective construction of solutions. Since these sustainability problems are multi-dimensional, the diverse stakeholders necessary for successful implementation of a solution need to be integrated at the early stages of development.

Good Practise Case: Concrete tools for supporting systems thinking

From Université de Technologie de Troyes (UTT) to Institut Mines-Télécom - Mines Albi (IMT-Mines Albi) in France and beyond at ATU, educators emphasise the importance of equipping students with the necessary tools to assess the full environmental impact of materials, products, and systems. At UTT, for example, students are trained to understand both incoming and outgoing material flows, perform carbon assessments, and conduct life cycle analyses (LCA). These technical competences are reinforced with practical knowledge of software tools and mathematical models to enable students to apply these skills in real-world contexts.

The focus on LCA and related tools is particularly relevant for sectors such as construction and agricultural engineering. For example, ATU students learn about renewable energy systems, carbon counting, and moisture risk analysis as part of their training in sustainable construction. These skills allow them to assess energy performance and environmental risks comprehensively. IMT-Mines Albi echoes this sentiment by highlighting the importance of systemic thinking, which enables students to analyse interconnected systems, such as energy conversion and environmental impact, using LCA methodologies.

These technical competences are essential for modern professionals who are tasked with implementing sustainable practices across industries. By fostering expertise in LCA, carbon assessments, and sustainability tools, institutions are preparing students to make data-driven decisions that mitigate environmental impacts and contribute to long-term sustainability goals.

Many of the technical skills highlighted in the interviews attempt to approach systems thinking from a technical standpoint, such as through lifecycle analyses and the evaluation of technologies' environmental impacts throughout their lifecycle, from raw material extraction to recycling. Teaching these skills ensures that students understand both high-tech and low-tech solutions' social, environmental, and economic implications. One example highlighted how energy efficiency is crucial, but that considerations must be made as to whether certain technologies, like electric mobility, are the best solutions overall, considering social and environmental consequences.

Adopting a systems thinking mindset strengthens other key recommendations, particularly the development of a multidisciplinary approach. Systems thinking and multidisciplinarity reinforce one another by fostering a more comprehensive understanding of complex challenges. While multidisciplinarity brings together expertise from different fields to tackle problems from multiple perspectives, systems thinking ensures that these perspectives are meaningfully integrated rather than remaining isolated or fragmented. Systems thinking helps individuals recognize interconnections, feedback loops, and dependencies across disciplines, making multidisciplinary collaboration more effective. At the same time, multidisciplinary engagement expands the range of knowledge available for addressing sustainability challenges, ensuring that solutions account for technical, social, economic, and environmental dimensions. For sustainability-oriented challenges—particularly in engineering—combining these two approaches is crucial for developing solutions that are both technically sound and contextually informed, ensuring they function effectively within broader social and ecological systems.

3.2 Recommendation 2: Integrate Comprehensive Sustainability Knowledge Across Engineering Curricula

Engineering programmes often focus very strictly on teaching the technical competences necessary for students to have successful careers as engineers. Several of our interviewees reiterated the importance of providing students with comprehensive understandings of key sustainability principles, practices, and skills relevant to engineering. At the same time, one of the most common critiques of programmes already attempting to embed sustainability was that the programmes do not succeed at providing a holistic vision of sustainability. Similarly, engineering academics who teach on sustainability-oriented topics, but that do not explicitly discuss the sustainability agenda, were uncomfortable incorporating the topics if they would simply be done at a cursory level. Teaching foundational knowledge and understanding goes beyond the development of skills needed for sustainability-oriented careers, placing a greater emphasis on the history, contexts, and dynamics of sustainability within our society.

As discussed in Section 1, the concept of sustainability can be further broken down into social, environmental and economic aspects. Each of these, despite not always being directly linked to engineering, are affected by the work of engineers, effects that must in turn be understood, acknowledged, and incorporated by engineers as they develop solutions to engineering challenges. Some aspects of this may be fairly obvious, such as the potential opportunity to solve environmental problems or developing new sustainable economic and business models. Other aspects, such as cultural marginalisation and environmental justice, may not be so easily connected to concepts traditionally within the bounds of engineering.

Leading the drive to adjust the topics discussed and taught in engineering programmes is industry, with engineering firms consistently describing engineering students as emerging from their education with a foundation of technical skills, but consistently lacking sustainability-oriented skills and knowledge. By placing an educational burden on the private sector, the lack of sustainability knowledge by graduating students can slow the progress that industry makes towards achieving the SDGs and the broader sustainability agenda. Therefore, it is vital in engineering programmes to incorporate, or allow students to take, courses on social, environmental, and economic issues and allow students to attach these concepts to engineering problems through projects and other coursework. This will allow students to emerge from their education with the full set of knowledge, competences, and skills necessary to immediately contribute to solving sustainability challenges.

Good Practice Case: Directly Embedding Sustainability in Engineering Education

In response to student and industry demands, European higher education institutions (HEIs) have increasingly recognised the importance of exposing students to sustainability principles. The embedding of sustainability throughout their education ensures that students are equipped with the multidisciplinary knowledge necessary to address the environmental, social, and economic impacts of their future work.

Universities like those in the IMT Group in France enable students to address sustainability challenges through courses on environmental factors such as water, air, waste, and biodiversity. Institut-Mines-Télécom - Mines Albi (IMT-Mines Albi) complements this by offering courses on renewable energy systems, with practical training in energy performance assessments and life cycle analysis. Elsewhere, ATU encourages students to focus on environmentally conscious materials, not only to reduce waste but also to align with broader sustainability goals. This holistic approach ensures students consider both functionality and environmental impact in their projects.

Industry partnerships are also vital for exposing students to sustainability concepts during their education. Institutions like P. Porto offers internship programmes that expose students to real-world sustainability challenges early in their education, allowing students integrate sustainable practices into professional settings. Through partnerships between universities, industry, and government, students gain practical experience alongside theoretical knowledge, ensuring they are prepared to meet evolving workforce demands and sustainability regulations.

By integrating sustainability expertise into traditional technical studies, while simultaneously providing practical experiences, these programmes prepare students to design innovative engineering solutions that meet industry standards, while promoting the inclusion of sustainability. This cross-disciplinary approach equips graduates with the tools to address engineering challenges comprehensively, balancing both material and sustainability considerations.

3.3 Recommendation 3: Train Students in Sustainability-Related Skills

Skills related to sustainability that are currently being taught in the interviewed HEIs are covered extensively in section

2.2. above. While engineering programmes already cover the technical skills necessary for students to hold successful careers as engineers, more focus must be put on developing engineering skills, both technical and transversal, related to sustainability. In recognition of the fact that curriculum is often set by institutions outside of HEIs, leaving little room for the addition of new content, educator could focus on the areas of overlap between the skills required in the set curriculum and sustainability-related skills.

The ideal sustainability-related skills include those listed in this report, and will be covered extensively in the Embedding Sustainability Competences Research Report which will be published alongside this Discovery Report as part of the Engineering Education for a Sustainable Future project.

04 Conclusions

The data gathered through interviews and extensive academic research highlights that the path to embedding sustainability in engineering education requires an actionable, system-wide approach. To achieve meaningful change, Higher Education Institutions (HEIs) must shift toward competency-based learning models that prioritize sustainability, encourage multidisciplinary collaboration, and promote curriculum redesigns focused on sustainability-oriented pedagogies.

Good Practise Case: Multidisciplinary Approaches to Sustainability Education

The integration of sustainability into higher education necessitates a multidisciplinary approach that transcends individual departments and curricula. Both educational Institutions like Université de Technologie de Troyes (UTT) in France and industry members such as Wind Energy Ireland (WEI) have found that sustainability issues cannot be addressed through isolated knowledge streams, but require collaboration across disciplines such as engineering, environmental sciences, and business management. By fostering such multidisciplinary learning, students gain a broader perspective on how their specialised knowledge contributes to solving global sustainability challenges.

Incorporating sustainability across all engineering topics, while challenging, promotes holistic thinking and innovation. The benefits extend beyond just technical skills; students also develop a deeper understanding of ethical, social, and environmental impacts of their work. This holistic perspective enables them to make more informed and sustainable decisions, whether in construction, energy, or environmental management.

Additionally, fostering collaboration between university departments can better prepare students to handle the complexity of real-world sustainability issues. For instance, integrating case studies and hands-on projects that simulate real-world scenarios helps students collaborate with and integrate partners from different fields such as law or economics. These experiences not only improve their problem-solving skills but also encourage lifelong learning, as graduates recognise the need to collaborate with actors from outside their discipline. Ultimately, multidisciplinary approaches empower students to become innovative leaders in sustainability by forcing them to think beyond the traditional boundaries of engineering.

Embedding sustainability is not just about adding content to existing courses but transforming the way engineering is taught and learned. This involves integrating sustainability across every facet of engineering education, from course design to grading rubrics and student projects. Universities should actively seek collaborations with industry to create project-based learning opportunities that reflect real-world sustainability challenges, preparing students to tackle complex, multifaceted problems from day one in the workforce.

To ensure sustainability becomes a cornerstone of engineering education, a concerted effort is required from all stakeholders. Policymakers and accrediting bodies need to push for more stringent sustainability requirements, while HEIs must invest in faculty training and resources to equip teacher-researchers with the skills needed to teach these concepts effectively. Equally important, students must be encouraged to take ownership of their role in sustainability, fostering an ethos of environmental stewardship and social responsibility.

The real impact of embedding sustainability lies in its ability to challenge traditional methods and ignite innovative thinking. Students trained in this way emerge not only with technical skills but with a deep understanding of the societal and environmental consequences of their work. Collaborative, multidisciplinary projects further equip future engineers to confront the sustainability challenges of our time with creativity and resilience.

Ultimately, embedding sustainability in engineering education is more than a curriculum adjustment; it is a shift in mindset that will define the engineers of tomorrow. This transformation holds the potential to revolutionise both engineering education and the industry, fostering graduates who are not only equipped for success but committed to driving societal progress and environmental sustainability. This systemic shift, supported by ongoing collaboration between HEIs and industry, will ensure that engineering education continues to evolve, producing graduates capable of delivering innovative solutions to today's most pressing challenges.

Based on these conclusions, the EESF consortium partners will develop a package of Online Educational Resources (OERs) to assist in the embedding of sustainability in engineering programmes. Heavily influenced by the recommendations elucidated in Section 3, the OERs will provide practical solutions for engineering educators which are adaptable to their individual contexts and competences. This will ensure that the results of the EESF project can be adopted across as many institutions as possible, accounting for varying national and institutional policies regarding course modules and content. The OERs developed will also account for other aspects discussed in the Discovery Report, including the personal motivations, desires, and concerns of teacher researchers, level of embeddedness of sustainability in existing institutional and programme structures, and industry needs. By embedding sustainability into the core of their programmes, institutions can help shape the next generation of engineers—engineers for good, and for a sustainable future.

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