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Linking SDGs, Competencies, and Learning Outcomes: A Tool for Curriculum Alignment in Higher Education

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Abstract

This paper presents a structured strategy for integrating the Sustainable Development Goals (SDGs) into university courses by linking them to competencies and learning outcomes. The proposed methodology, based on fuzzy logic, evaluates the degree of alignment between teaching activities and selected SDGs through matrices that connect competencies with assessment activities and expected learning outcomes, improving the gap regarding the inclusion of the SDGs and their articulation in terms of competencies. The approach was applied to two subjects from the Master's Degree in Renewable Energy and Energy Efficiency at the Distance University of Madrid: "Electricity Market" and "Wind Energy". In both cases, the learning outcomes were redesigned, and the activities were adjusted to ensure meaningful incorporation of sustainability principles into the curriculum. The method enables quantification of each activity's contribution to the SDGs and supports a critical review of curriculum design to ensure coherent integration. The results indicate that project-based activities show the highest alignment with the SDGs, particularly with Goals 7, and 12, which achieve an average rating of 0.7 (high). The developed tool provides a practical and replicable solution for sustainability-oriented curriculum planning and can be adapted to other disciplines and educational programs.

Keywords: sustainable development goals (SDGs); higher education; competency-based learning; learning outcomes; curriculum design; fuzzy logic

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1. Introduction

Higher-education institutions (HEIs) are increasingly being called upon to go beyond their traditional academic roles and actively participate in addressing the global challenges set out by the United Nations' 2030 Agenda [1]. This transformation involves not only raising awareness of the Sustainable Development Goals (SDGs) but also embedding them across teaching, research, institutional management, and community engagement. Given their capacity to educate future professionals, generate knowledge, and drive innovation, universities are in a unique position to contribute meaningfully to sustainable development [2].

A key dimension of this contribution lies in curricular reform, where sustainability must become more than a thematic addition: it must serve as a guiding principle in the teaching and learning process. As the UNESCO highlights [3], education for sustainable

development (ESD) demands an intentional alignment between pedagogical approaches, learning outcomes, and competencies, allowing students to acquire not only cognitive knowledge but also the values, skills, and attitudes essential for sustainability. In response, various initiatives have emerged to support the curricular inclusion of the SDGs in higher education, often through interdisciplinary approaches, active learning methods, and redefinition of learning outcomes [4]. However, practical frameworks remain lacking that provide systematic, scalable, and flexible tools for assessing how, and to what extent, these goals are integrated into educational activities.

In this context, methodological frameworks that facilitate the integration of SDGs into curriculum design offer valuable tools for advancing the institutional commitment to the 2030 Agenda.

The present work aims to propose an effective strategy for integrating the SDGs into university courses by establishing a coherent link between the SDGs, competencies, learning activities, and outcomes. The main scientific contribution lies in the development of an analysis tool based on fuzzy logic, which allows for a nuanced and precise evaluation of the degree of alignment between teaching activities and selected SDGs. This approach supports the revision and redesign of learning outcomes, encouraging a structured and systematic incorporation of sustainability into curriculum planning.

2. Research Background

Table 1 shows the related research on the integration of the SDGs in higher education, highlighting key approaches, tools, and findings.

To identify the studies, a structured literature review was conducted following the PRISMA methodology [5]. The search strategy combined keywords related to "Sustainable Development Goals", "higher education", "curriculum", and "engineering courses" using Boolean operators. Searches were carried out in Scopus, Web of Science, and Google Scholar, covering the period from 2019 to 2025 (Q1 and Q2).

The initial search yielded a total of 1125 records. After removing duplicates, 550 unique studies were screened based on titles and abstracts. In this phase, studies were excluded if they were not directly related to higher education or did not explicitly address the integration of SDGs in teaching or curriculum design. A total of 55 articles were retained for full-text review. Following a detailed eligibility assessment, 28 studies met the inclusion criteria, which required that (i) the work explicitly connected higher education (STEM) practices with one or more SDGs, and (ii) the study reported empirical results or a documented methodological approach that could be compared across cases.

Starting the background research in 2019, two studies were found that analyze the alignment of undergraduate and graduate curricula with the SDGs. The University of Strathclyde presented its experience with degree courses that combine an innovative pedagogy called vertically integrated projects with the SDG framework [6]. At the University of Belgrade [7], the curriculum of the Master's in Integrated Urbanism program at the Faculty of Architecture was assessed against SDG 11 targets and related learning objectives, defining several key aspects to improve them. An interesting experience was the collaboration between students of the Master of Science in Sustainable Energy Development (University of Calgary) with Burkina Faso Power Hub [8], which enabled students to acquire competencies in sustainability while contributing to the achievement of SDGs 4, 7, 8, 9, and 17 (refer to Section 4 for SDG classification).

Table 1. Summary of research studies. STEM: Science, Technology, Engineering, and Mathematics. LO: learning outcome. ✓: The paper includes the topic. ✗: The paper doesn't include the topic.

Year	Ref.	STEM	LO
2019	[6]	✓	✗
	[7]	✓	✓
	[8]	✓	✗
2020	[9]	✓	✓
	[10]	✓	✓
	[11]	✗	✗
	[12]	✓	✗
2021	[13]	✗	✓
	[14]	✓	✗
	[15]	✓	✓
	[16]	✓	✗
2022	[17]	✗	✓
	[18]	✓	✗
	[19]	✓	✗
	[20]	✓	✗
	[21]	✓	✗
2023	[22]	✓	✗
	[23]	✓	✗
	[24]	✓	✗
	[25]	✓	✗
	[26]	✗	✗
2024	[27]	✓	✗
	[28]	✓	✗
	[29]	✓	✗
	[30]	✓	✗
	[31]	✓	✗
2025	[32]	✓	✗
	[33]	✗	✗

In 2020, various studies addressed the integration of the SDGs in higher education from different perspectives and regions. For instance, a tool based on Analytic Hierarchy Process (AHP) was developed to assess how master's programs contribute to the SDGs, identifying gaps in areas such as health, inclusion, and collaboration in Europe and the UK, highlighting the need to improve sustainability-oriented education [9]. Additionally, a logical framework was proposed to embed the SDGs in engineering education, including examples and recommendations to strengthen their presence in curricula and higher-education institutions [10]. In the African context, the key role of higher-education institutions in Southern Africa was emphasized for training innovative leaders through interdisciplinary, participatory, and problem-based approaches that facilitate SDG implementation [11]. Lastly, a case study in Angola revealed that, although biology teacher education curricula do not explicitly integrate the SDGs, students' work reflects a localized commitment to several goals, suggesting ways to improve SDG inclusion in teacher training and educational research [12].

In 2021, studies based on a thorough analysis of course descriptions and learning outcomes were found. A competency map in sustainability with 58 learning objectives for Business Administration and Management was presented in [13], which defined a methodology that relates these learning objectives to the SDG learning objectives defined by the UNESCO. Other articles focused on how to incorporate SDG 5 (gender equality)

into engineering [14] and STEAM [15] studies to make them interesting for women and overcome the gender gap. Extensive studies were also found that analyzed the status of the 17 SDGs in academic institutions, such as the one carried out at the University of Melbourne's School of Engineering, in which six university schools offering over 2157 subjects were investigated [16].

In 2022, a comparative study identified five key approaches for incorporating the SDGs into both online and face-to-face teaching: curriculum redesign, student experience orientation, alignment of learning outcomes, institutional leadership, and network participation [17]. These strategies resonate across various disciplines, such as mechanical engineering, where specific indicators were proposed to assess the level of SDG integration and guide institutional decision-making [18]. A practical example of implementation is the initial diagnostic conducted by the Universitat Politècnica de València (UPV), which analyzed the presence of SDGs in a master's program in industrial engineering, aiming to redesign learning activities and foster more sustainable teaching practices [19]. Simultaneously, in the faculties of Education Sciences at Andalusian public universities, a replicable methodology was developed to measure the degree of curricular greening, highlighting the methodological and organizational challenges of integrating sustainability from a systemic perspective [20]. Finally, disciplines like physics have also started to incorporate the SDGs as motivational tools for students by contextualizing learning through thematic challenges and combining face-to-face and online methodologies, as exemplified by the use of the PoliformaT platform at UPV [21].

In 2023, a systematic review of research articles examining the integration of the SDGs in higher-education institutions was published [22]. The study showed higher-education institutions' concerns about measuring the impact of their activities in relation to the SDGs using different methodologies, such as the analysis of normative and academic documents, questionnaires, interviews, and workshops. One of the main findings of this work was the limited scientific production from developing countries, with 56% of the publications originating in European countries, with Spain being the most prominent (31%). The study concluded that, to accelerate the implementation of the SDGs in higher education, it is necessary to foster synergies in research and knowledge transfer between developed and developing countries. Some of the analysis methodologies reflected in this work can be found in [23], which presented research on university students' knowledge and awareness of the SDGs by analyzing the opinions of students from several undergraduate and master's programs, proposing teaching and learning activities capable of improving the results obtained. The study in [24] proposed a model for the evaluation of dissertations and theses in relation to the SDGs of graduate programs in the area of environmental sciences in Brazil. The study in [25] addressed a broad review of the teaching guides for industrial engineering disciplines, determining the weights that the SDGs have in the current configuration of their content. The study in [26] explored the integration of the SDGs into teacher training programs at the Faculty of Education of Okayama University and at the University of Ljubljana by analyzing 2583 curricula and conducting interviews.

In 2024, various studies addressed the integration of the SDGs into engineering education, emphasizing active methodological strategies and the role of faculty. One prominent line of research is the incorporation of SDGs through multidisciplinary projects and active learning methodologies. A methodology was developed to design SDG-aligned activities across eight courses in a bachelor's program in Industrial Electronics and Automation Engineering. The initiative, centered around analyzing thermal comfort and energy use in a faculty building, helped students to connect their skills with real-world sustainability problems and increased their awareness of the SDGs [27]. Similarly, in a process engineering course within a Master's in Industrial Engineering, the SDGs were integrated

through active methods, such as project-based learning, collaborative work, and flipped classrooms. This approach enhanced student motivation and performance while deepening their understanding of SDGs related to energy and climate change [31]. A second area of study focused on faculty perceptions and innovation projects. In one case, faculty members at an industrial engineering school were surveyed to evaluate how well the SDGs were integrated into undergraduate programs. The results revealed that some SDGs, such as Responsible Consumption and Production (SDG 12), Affordable and Clean Energy (SDG 7), and Clean Water and Sanitation (SDG 6), were more widely addressed than others. It also identified specific degrees with the highest number of courses meaningfully incorporating multiple SDGs [28]. Another innovation project applied project-based learning (PBL) in a mechanical engineering course in a Master's in Mechatronics. The goal was to strengthen both transversal competencies and SDG integration. Surveys and interviews highlighted the need to further develop active methodologies to align the course with labor market demands and sustainability goals [29]. Finally, a broader international study examined faculty perspectives on sustainability education at a U.S. public university. Using a decision-making model, the study found that the integration of SDGs in engineering education was primarily driven by individual initiative rather than institutional or external pressure. This bottom-up approach demonstrated potential, but it also underscored the limitations of relying solely on individual efforts without stronger systemic support [30].

Finally, in the first quarter of 2025, the use of PBL activities stands out to increase knowledge and perception of the SDGs in higher education [32,33]. Taken together, these experiences demonstrate a transversal and multifaceted trend toward the effective incorporation of the SDGs in higher education, which is essential for addressing global challenges through academic training.

Out of the twenty-eight studies analyzed, twenty-three (82%) focus on STEM disciplines, indicating a strong interest in integrating sustainability into technical and scientific fields. However, only six studies (21%) explicitly address learning outcomes, revealing a significant gap between the thematic inclusion of the SDGs and their articulation in terms of expected student competencies. This discrepancy suggests that, while the SDGs are present in the broader educational focus of many programs, more effort is needed to ensure they are clearly and measurably reflected in learning outcomes.

3. Methodology

The proposed methodology for introducing the SDGs in subjects takes into account not only the commitment to disseminating these goals among students but also their consideration as learning tools (Figure 1). This is achieved by linking the SDGs related to the course with the competencies being developed, both transversal and general or specific. In this way, students will incorporate sustainability into the skills acquired for their professional development as the basis for all actions. The introduction of the SDGs in the subjects implies that they are addressed in the assessment activities in the same way that the competencies are developed. To achieve this, based on the identification of the competencies developed in each of the subject's activities, the implemented methodology follows these steps:

1. **Identification of relevant SDGs.** SDGs related to the subject are selected through in-depth reflection among the teaching staff, considering technological, social, and environmental aspects. Formally, we define a pertinence vector

$$\mathbf{p} = (p_1, \ldots, p_G), \qquad p_g = \begin{cases} 1 & \text{if SDG } g \text{ is considered relevant,} \\ 0 & \text{otherwise,} \end{cases} \tag{1}$$

where G denotes the total number of SDGs.

2. **Competencies–SDGs correspondence.** The next step consists of establishing the relationship between subject competencies and SDGs. This is represented by a correspondence matrix:

$$\mathbf{M}_{CS} \in \{0,1\}^{C\times G}, \qquad (\mathbf{M}_{CS})_{c,g} = \begin{cases} 1 & \text{if competence } c \text{ contributes to SDG } g, \\ 0 & \text{otherwise,} \end{cases} \tag{2}$$

where C is the total number of competencies. In cases where the relationship is not strictly binary, $(\mathbf{M}_{CS})_{c,g} \in [0,1]$ can be used to reflect partial contributions.

3. **Competencies–activities correspondence and cross with SDGs.** For each activity $a \in \{1,\ldots,A\}$, we define the competencies–activities matrix:

$$\mathbf{M}_{CA} \in \{0,1\}^{C\times A}, \qquad (\mathbf{M}_{CA})_{c,a} = \begin{cases} 1 & \text{if activity } a \text{ develops competence } c, \\ 0 & \text{otherwise.} \end{cases} \tag{3}$$

The raw relationship between activities and SDGs is then obtained through matrix multiplication:

$$\mathbf{F} = \mathbf{M}_{CA}^{\top}\mathbf{M}_{CS}, \qquad F_{a,g} = \sum_{c=1}^{C} (\mathbf{M}_{CA})_{c,a} \cdot (\mathbf{M}_{CS})_{c,g}. \tag{4}$$

Here, $F_{a,g}$ represents the frequency (or intensity) with which activity a is linked to SDG g via the competencies involved.

4. **Normalization and fuzzy scale.** To make the results comparable, raw frequencies are normalized:

$$S_{a,g} = \frac{F_{a,g}}{\max_{g'} F_{a,g'} + \varepsilon}, \qquad \varepsilon > 0. \tag{5}$$

The normalized values $S_{a,g} \in [0,1]$ are then mapped to a fuzzy linguistic scale that captures the degree of alignment between each activity and the SDGs [34]:

$$\widehat{S}_{a,g} = \begin{cases} 0.0 & \text{if } S_{a,g} = 0 \quad \text{(Null)} \\ 0.1 & \text{if } 0 < S_{a,g} \leq 0.2 \quad \text{(Very low)} \\ 0.3 & \text{if } 0.2 < S_{a,g} \leq 0.4 \quad \text{(Low)} \\ 0.5 & \text{if } 0.4 < S_{a,g} \leq 0.6 \quad \text{(Medium)} \\ 0.7 & \text{if } 0.6 < S_{a,g} \leq 0.85 \quad \text{(High)} \\ 1.0 & \text{if } S_{a,g} > 0.85 \quad \text{(Very high).} \end{cases} \tag{6}$$

The result of this step is the *normalized activities–SDGs matrix*, which provides a systematic and visual evaluation of the alignment of each activity with the selected goals.

5. **Redesign of learning outcomes.** The normalized matrix is used to identify both overrepresented SDGs (consistently high values) and underrepresented ones (low or null values). This information guides the reformulation of learning outcomes (LOs):

$$LO^{\text{new}} = f\left(LO^{\text{initial}}, \widehat{S}_{a,g}\right), \tag{7}$$

where $f(\cdot)$ denotes the adaptation process that integrates SDG-related content into the learning outcomes. When a key SDG is absent, new LOs are defined to explicitly incorporate it, thus ensuring curricular coherence and alignment with sustainability principles.

The basis of this methodology was presented for the analysis of a particular case in Ref. [35]. In this work, significant enhancements have been implemented to ensure that it is standardized and measurable.

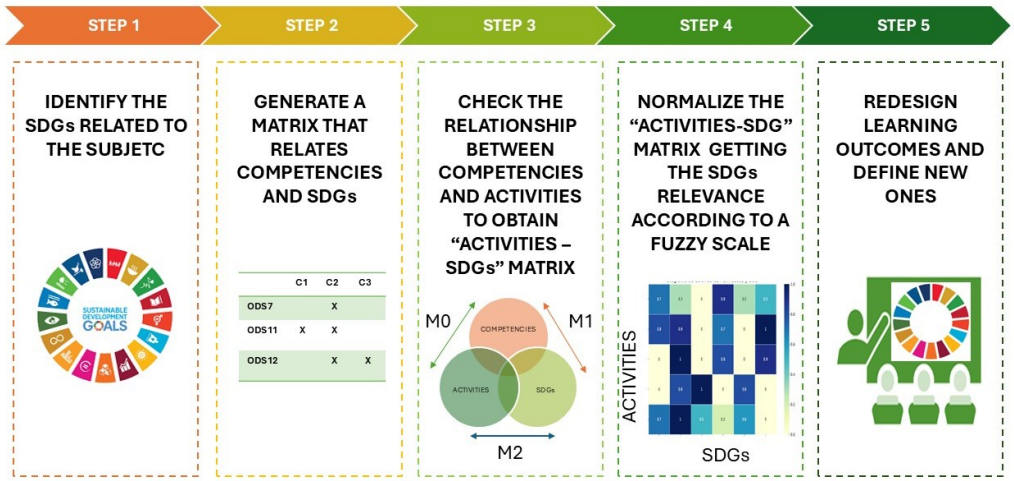


Figure 1. Architecture of the proposed methodology.

4. Case Study

The developed methodology has been applied to two subjects of the Master's Degree in Renewable Energy and Energy Efficiency at UDIMA, which is a distance learning university master's degree aimed at a professional student profile. This aspect makes the integration of the SDGs into the curriculum more interesting as they would be directly applied to the professional activities of the students.

The subjects selected for the implementation of the methodology are "Electricity Market" and "Wind Energy", covering the two areas of the master's program: renewable energy and energy management and efficiency. To perform the analysis, the SDGs are grouped into four thematic blocks as follows [36]:

- **Block I: Poverty, Inequality, and Social Development**
  This block includes key areas such as Poverty Eradication (SDG 1), Zero Hunger (SDG 2), Good Health and Well-Being (SDG 3), Quality Education (SDG 4), and Reduced Inequalities (SDG 10).
- **Block II: Economic Development and Employment**
  This block addresses topics related to Economic Growth and Decent Work (SDG 8), Industry, Innovation, and Infrastructure (SDG 9), as well as Responsible Consumption and Production (SDG 12). According to [36], this reflects a new development model centered on equality and sustainability.
- **Block III: Environment and Climate Change**
  This block covers issues such as Affordable and Clean Energy (SDG 7), Clean Water and Sanitation (SDG 6), Sustainable Cities and Communities (SDG 11), Responsible Consumption and Production (SDG 12), Climate Action (SDG 13), Life Below Water (SDG 14), and Life on Land (SDG 15).
- **Block IV: Cross-Cutting Themes**
  This includes Gender Equality (SDG 5), Peace, Justice, and Strong Institutions (SDG 16), and Partnerships for the Goals (SDG 17). These themes are considered essential and cross-cutting across all the previous blocks.

In accordance with cross-curricular (or transversal) competencies (TCs), closely related to STEM studies, the Master's Degree in Renewable Energy and Energy Efficiency (regulated in BOE nº 67 2014) focuses on the following:

TC1 Problem-solving skills that arise in professional practice.
TC2 Analytical and synthetic skills.
TC3 Critical and deductive reasoning.
TC4 Autonomous learning.
TC5 Encourage creativity, initiative, and proactivity.
TC6 Ethical commitment.

4.1. "Electricity Market" Case

To identify the SDGs related to the "Electricity Market", a comprehensive overview of technological, social, and environmental aspects of electrical energy exchanges has been analyzed. The SDGs involved in block III are predominant, but the objectives connected to the other blocks are also identified. Specifically, in block III, the objectives Affordable and Clean Energy (SDG 7), Sustainable Cities and Communities (SDG 11), Climate Action (SDG 13), and Responsible Production and Consumption (SDG 12) are related to the topic. Regarding the other blocks, SDG 12 is common to block II, SDG 4 (Quality Education) must be present when defining competencies and activities, and SDG 17, which is part of the cross-cutting block, is also included.

In addition to the transversal competencies common to the master's degree, the subject works on a series of general (GC) and specific (SC) competencies associated with "learning by going":

GC1 Ability to manage and analyze relevant bibliography on the topic, published both nationally and internationally.
GC2 Ability to integrate knowledge and address the complexity of formulating reasoned judgments in the field based on information that may be incomplete or limited.
SC1 Ability to analyze the role of energy as a fundamental factor of production in the economic system and the functioning of various energy markets.
SC2 Ability to carry out efficient energy management of a production system.
SC3 Ability to perform financial analysis applied to the energy sector.
SC4 Ability to conduct electricity market studies and pricing and apply these studies to reduce a system's energy costs.

Table 2 shows the matrix that relates the competencies described above to the identified SDGs.

Table 2. Electricity market competencies–SDGs matrix.

	SDG 4	**SDG 7**	**SDG 11**	**SDG 12**	**SDG 13**	**SDG 17**
GC1	X	X	X	X	X	
GC2	X	X	X	X	X	
SC1		X		X		X
SC2		X		X	X	
SC3		X	X	X		
SC4		X	X	X		
TC1	X	X	X	X	X	
TC2	X	X	X	X	X	
TC3	X	X	X	X	X	
TC4	X		X	X		
TC5	X		X	X		
TC6	X	X	X	X	X	X

The assessment activities carried out in the subject of "Electricity Market" are the following:

- Social impact project consisting of two evaluation stages (AEC1 and AEC2).

- Case study evaluation (AA1).
- Applied research (computer practice) (AA2).
- Written test (self-assessment tests C1 and C2, and final written exam E1).

Based on the current identification of the competencies addressed in each subject activity (Table 3), the SDG activities cross-matrix is obtained. The normalized matrix of SDG activities, according to the scale proposed in Section 3, is shown in Figure 2.

Table 3. Electricity market competencies–activities matrix.

	AEC1	AEC2	C1	C2	AA1	AA2	E1
GC1	X	X	X	X	X		X
GC2	X	X	X	X	X	X	X
SC1	X	X	X	X		X	X
SC2	X	X			X		X
SC3		X	X			X	X
SC4		X	X			X	X
TC1	X	X	X	X		X	X
TC2	X	X	X	X	X	X	X
TC3	X	X	X	X		X	X
TC4	X	X			X	X	
TC5	X	X					
TC6	X	X					

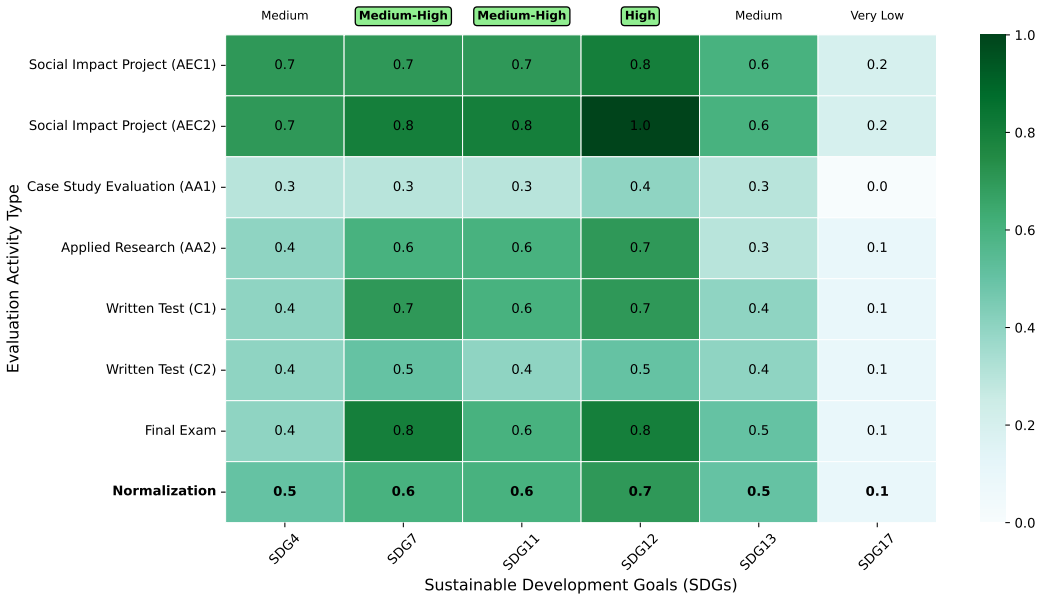


Figure 2. Normalized activities: SDG matrix for "Electricity Market" case: visualization of the fuzzy alignment degrees (null, very low, low, medium, high, and very high) between each academic activity and the selected Sustainable Development Goals.

The main conclusion of the analysis is the importance of SDG 12 in the subject, compared to SDG 7, which, based on a cursory analysis, could be considered the most relevant. This demonstrates that a careful analysis is necessary to effectively introduce the SDGs into the curriculum. This integration must be transversal to improve the relationship between SDG 17 and activities, which is the lowest.

The results in Figure 2 show how project-based activities directly relate to the SDGs, achieving scale values ranging from medium (0.6) to high (1.0) for most goals. Due to their practical and real-life approach, which allows students to apply their knowledge to energy efficiency and energy cost issues identified in their environment, these activities

address sustainability and enhance competencies in this area. The weakest relationship with the SDGs is obtained for the case study activity (0.3 value), which aims to apply new technologies in the field of energy storage without discussing the advantages and disadvantages of its application in the global energy system, reflecting that, to correctly introduce the SDGs in the curriculum, it is essential to contextualize by modifying the learning outcomes.

Therefore, to incorporate the SDGs into the subject activities, it is necessary to define new learning outcomes associated with these sustainability objectives. The learning outcomes intended to be achieved in the traditional approach to the subject through the different activities, as well as those designed after the curricular implementation of the SDGs, are detailed below.

Initial Learning Outcomes

- Understand the current electricity market and its pricing (AA2, AEC2, C1, and E1).
- Apply new technologies in the field of energy storage (AA1).
- Use financial analysis tools applied to the energy sector (AEC2, C1, and E1).
- Develop an energy-efficient production system (AEC1, AEC2, C1, C2, and E1).

SDG Learning Outcomes

- Understand energy supply markets by analyzing their accessibility, security, and sustainability (AA2, AEC2, C1, and E1).
- Apply new technologies in the field of energy storage as a tool to guarantee a secure and sustainable energy supply (AA1).
- Use financial analysis tools applied to the implementation of sustainable production systems and the improvement of energy efficiency in buildings (AEC2, C1, and E1).
- Develop a sustainable energy production system, ensuring an affordable, secure, and decarbonized energy supply (AEC1, AEC2, C1, C2, and E1).
- Identify and classify the information and tools available for the analysis of sustainability and energy efficiency in buildings and processes (AEC1 and AEC2).

It is worth noting that, in addition to reformulating the initial learning objectives, a new one aligned with SDG 4 has been added. Identifying new learning outcomes associated with the SDGs facilitates modifying the activities to integrate them. The following modifications have been incorporated:

Strengthen, in social impact project activities, their real application to society by disseminating the results in the students' professional and personal environments to better integrate SDG 12.

Emphasize the importance of accessibility to energy sources when studying energy markets, an aspect often overlooked when studying established energy markets. This aspect will be addressed in the written tests, reinforcing SDG 7.

In the case study activity, focus on the use of energy storage at the local level, aiming to integrate SDG 11, related to sustainable cities.

To emphasize SDG 13, complete the computer practice on electricity pricing by calculating the carbon footprint of energy purchases.

Finally, review the databases, bibliographic sources, and tools provided to students to complete the project work activities, checking their availability, updating, and continuous improvement, thus constituting a source of ongoing learning in accordance with SDG 4 once they complete the master's degree.

4.2. "Wind Energy" Case

To identify the SDGs related to the "Wind Energy" course, a comprehensive analysis was conducted, considering the technological, environmental, social, and economic aspects involved in electricity generation from wind power. The course addresses not only the development and operation of wind technologies but also their role in the energy transition, their contribution to environmental sustainability, and their impact on economic and social development. This approach makes it possible to establish clear links with the SDGs.

The transversal competencies (TC1–TC6) are common to the master's degree. The GCs and SCs are the following:

GC1 Ability to manage and analyze relevant literature on a topic related to one or more areas of renewable energy and energy efficiency, published both nationally and internationally.

GC2 Ability to adequately interpret society's expectations regarding the environment and climate change, as well as to engage in technical discussions and critical opinions on energy aspects of sustainable development as essential skills for professionals in the field of renewable energy and energy efficiency.

GC3 Ability to integrate knowledge and face the complexity of making well-reasoned judgments in contexts applicable to a company in the renewable energy and energy efficiency sector based on information that may be incomplete or limited.

SC1 Ability to understand the current landscape of wind energy as well as the technology required to generate electrical energy through wind turbines and feed it into the grid.

SC2 Ability to evaluate different renewable resources as sources for energy exploitation in a given real-world system.

SC3 Ability to analyze the various available technologies and manufacturers for creating renewable energy exploitation systems, and to critically distinguish and select quality options based on cost and real-world application.

Table 4 shows the matrix that relates the competencies described above to the identified SDGs.

Table 4. Wind energy competencies–SDGs matrix.

	SDG 4	**SDG 7**	**SDG 8**	**SDG 9**	**SDG 11**	**SDG 12**	**SDG 13**	**SDG 17**
GC1	X	X	X	X	X	X	X	
GC2	X	X		X	X		X	
GC3	X	X		X	X		X	
SC1		X		X	X	X		X
SC2		X		X	X	X		
SC3		X	X	X	X	X	X	
TC1	X	X	X	X	X	X	X	
TC2	X	X	X	X	X	X	X	
TC3	X	X	X	X	X	X		
TC4	X				X	X		
TC5	X				X	X		
TC6	X	X	X	X	X	X	X	X

The assessment activities carried out in the subject of "Wind Energy" are the following:

- Social impact project consisting of two evaluation stages (AEC1 and AEC2).
- Case study evaluation (AA1).
- Research activity (AA2).
- Written test (self-assessment tests C1 and C2, and final written exam E1).

Based on the current mapping of competencies addressed in each activity of the course (see Table 5), a cross-matrix linking activities to the SDGs is constructed. The normalized

matrix of SDG-related activities, following the scale outlined in Section 3, is presented in Figure 3.

Table 5. Wind energy competencies–activities matrix.

	AEC1	AEC2	C1	C2	AA1	AA2	E1
GC1	X	X	X	X	X	X	X
GC2	X	X	X	X	X	X	X
GC3	X	X	X	X		X	X
SC1	X		X				X
SC2	X		X	X		X	X
SC3	X	X	X	X		X	X
TC1	X	X	X	X	X	X	X
TC2	X	X	X	X		X	X
TC3	X	X	X	X	X	X	X
TC4	X	X				X	
TC5	X	X			X		
TC6	X	X					

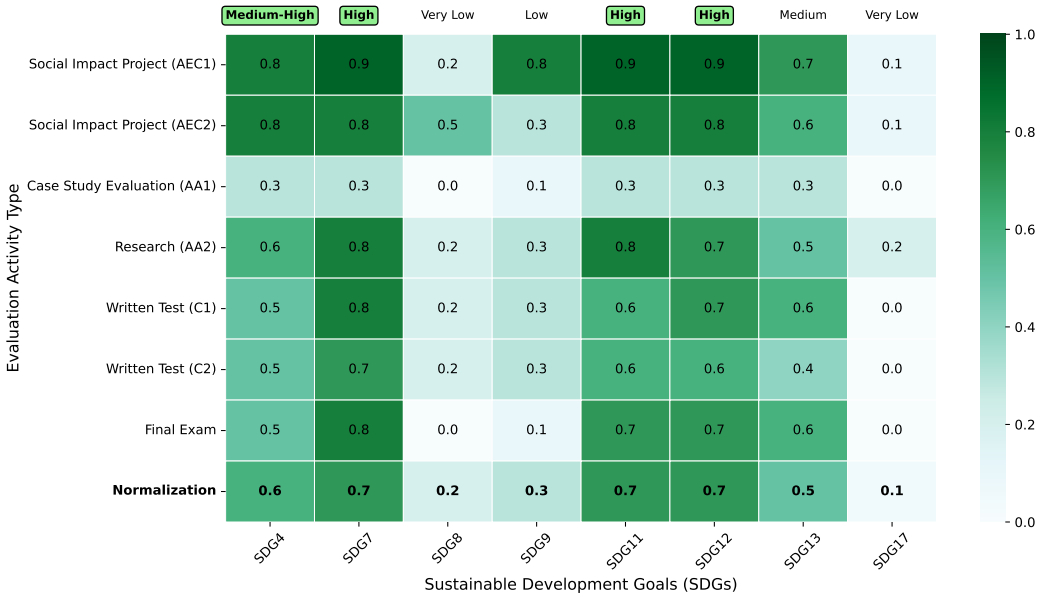


Figure 3. Normalized activities–SDGs matrix for "Wind Energy" case: visualization of the fuzzy alignment degrees (null, very low, low, medium, high, and very high) between each academic activity and the selected Sustainable Development Goals.

The relevance of SDGs 7 (Affordable and Clean Energy), 11 (Sustainable Cities and Communities), and 12 (Responsible Consumption and Production) stands out clearly in the context of wind energy education. This alignment is especially relevant given the direct relationship between wind energy systems and the need for clean, sustainable, and responsibly managed energy infrastructures in modern societies.

While SDG 13 (Climate Action) registers only a medium level of integration (normalized score of 0.5), its importance should arguably be on par with the aforementioned goals. Wind energy is a cornerstone technology for climate change mitigation, so activities related to this field should more explicitly emphasize its role in addressing climate action challenges. The discrepancy between the actual relevance of SDG 13 and its lower integration score suggests an area for pedagogical enhancement. The matrix also reveals how different activity types contribute to SDG engagement. For instance, social impact projects (AEC1 and AEC2) show the highest alignment with the prioritized SDGs—especially SDG 7

(0.9 and 0.8, respectively), SDG 11 (0.9 and 0.8), and SDG 12 (0.9 and 0.8)—highlighting the effectiveness of experiential interdisciplinary approaches in reinforcing sustainability competencies. In contrast, written assessments (C1, C2, and E1) show more moderate contributions, particularly in terms of SDG 13, where the values remain between 0.4 and 0.6. Normalized across all the activities, the final profile indicates a high integration of SDGs 7, 11, and 12; moderate engagement with SDG 13; low representation of SDG 9 (Industry, Innovation, and Infrastructure); and very low integration of SDG 17 (Partnerships for the Goals), which scores only 0.05. This points to potential areas of improvement, particularly in fostering collaboration and innovation frameworks within the educational context of wind energy.

In order to effectively integrate the SDGs into course activities, it is essential to define new learning outcomes aligned with these objectives. Below, a comparison between the learning outcomes traditionally pursued through the existing course methodology and those targeted following the incorporation of the SDGs is presented.

Initial Learning Outcomes

- Know how to manage and maintain renewable energy production facilities (AEC1, AEC2, C1, C2, and E1).
- Determine the advantages and disadvantages of the different technologies and manufacturers available for creating renewable energy exploitation systems (AA1, AA2, AEC2, C1, and E1).
- Perform structural calculations of support systems for renewable energy production facilities (AEC1 and C2).

SDGs Learning Outcomes

- Know how to manage and maintain renewable energy production facilities, promoting universal access to affordable, safe, sustainable, and modern energy, and fostering responsible practices in urban and rural environments (AEC1, AEC2, C1, C2, and E1).
- Critically evaluate the advantages and disadvantages of different technologies and manufacturers available for the development of renewable energy systems, integrating criteria of sustainability, energy efficiency, and responsible production and consumption (AA1, AA2, AEC2, C1, and E1).
- Perform structural calculations of support systems for renewable energy facilities, considering their environmental impact and promoting resilient solutions to climate change (AEC1 and C2).
- Promote lifelong learning and critical thinking around renewable energy, ensuring inclusive and equitable quality education with a focus on sustainability (AA1, AA2, AEC1, AEC2, C1, C2, and E1).

In addition to the reformulation of the initial learning objectives, a new outcome aligned with SDG 4 (Quality Education) has been incorporated. The identification of learning outcomes explicitly linked to the SDGs facilitates the adaptation and redesign of course activities to ensure their effective integration. The following modifications are incorporated:

> The integration of the Sustainable Development Goals into the course has led to a meaningful evolution in the learning outcomes, emphasizing not only technical competencies but also critical thinking, sustainability, and social responsibility. The reformulation of existing outcomes and the addition of new ones strengthen the alignment with SDGs 4, 7, 11, 12, and 13. Specifically, the traditional objective of managing renewable energy facilities has been expanded to include the promotion of universal access to clean, safe, and modern energy, reinforcing the commitment to SDG 7 and SDG 11. Similarly, the analysis of renewable

energy technologies has shifted toward a more critical and sustainability-focused approach, incorporating efficiency and responsible production and consumption principles, which directly supports SDG 12. Structural design tasks now include environmental considerations and resilience to climate change, enhancing student awareness and action in relation to SDG 13. Furthermore, the incorporation of a new learning outcome related to continuous learning and critical reflection addresses SDG 4 by fostering inclusive and quality education oriented toward long-term sustainability. These changes enable a more comprehensive educational model, where technical excellence is complemented by ethical and environmental responsibility, preparing students to respond effectively to global challenges in the renewable energy sector, particularly within the context of wind energy.

5. Discussion

In recent years, the interest in integrating sustainable development into higher education is undeniable, as evidenced by the significant increase in the number of articles addressing the inclusion of the SDGs in higher-education institutions [22]. The main objective is to provide students with the knowledge and competencies necessary to address the SDGs related to their future profession, forming future leaders of sustainable development. The first step to achieving this goal is to diagnose the degree of sustainability integration in bachelor's and master's degree programs. The second step is to define a methodology for integrating them broadly, not only at the activity level but also at the curricular level, which requires reviewing learning outcomes. This process must follow a standardized, measurable, and cross-curricular methodology that is applicable to all the activities of the subject.

The methodology must be capable of being **standardized** across higher education. The results of background research showed that there are more studies to integrate the SDGs related to STEM disciplines, possibly due to their practical application, but sustainability will be gradually implemented in all undergraduate and graduate programs; hence, it must be competency-based, not activity-based, as several analyzed works show [19,21,32,33]. The development of the competencies–SDGs matrix for a given subject, such as those shown in Tables 4 and 5 of the examples provided, can be a very useful tool to identify the degree of integration of a particular SDG with the subject. In the case studies presented, the SDGs related to the subject were identified prior to their relationship with competencies, but it is also possible to expand the matrix to all 17 SDGs in a broader analysis. From the analysis of the case studies conducted, it is notable that general and transversal competencies are more integrated with the identified SDGs than specific competencies since the latter have a higher degree of specificity and are therefore related to fewer SDGs.

The methodology must be **measurable** throughout all its phases, both in the initial diagnosis and in the final integration results. For the diagnostic phase, the fuzzy logic-based scale improves previously applied procedures [35] and clearly shows the relationship between the activities and the related SDGs. In both cases ("Electricity Market" and "Wind Energy"), the need for a holistic view when working with the SDGs is evident as SDG 17 is the one with the lowest degree of relationship with the activities. The acquisition of sustainability competencies is measured through learning outcomes, so their reformulation is essential to fully integrate the SDGs into the curriculum. The UNESCO guide [3] identifies indicative learning objectives and suggests learning activities for each SDG, providing an interesting starting point, as shown, for example, in [13]. However, the learning objectives of the master's program analyzed, and certainly in general at the undergraduate and graduate levels, are more complex and relate to several SDGs at once. Therefore, it is considered necessary for teachers to reformulate the subject learning objectives based on

existing ones and introduce sustainability as a guiding principle. For example, regarding the subject "Electricity Market", the initial learning outcome "Develop an energy-efficient production system" is reformulated to "Develop a sustainable energy production system, ensuring an affordable, secure and decarbonized energy supply", which involves SDG 7, SDG 12, and SDG 13, or, regarding the subject "Wind Energy", the initial learning outcome "Know how to manage and maintain renewable energy production facilities" incorporates SDG 7, SDG 11, SDG 12, and SDG 13 by modifying it as follows: "Know how to manage and maintain renewable energy production facilities, promoting universal access to affordable, safe, sustainable, and modern energy, and fostering responsible practices in urban and rural environments." Moreover, defining a collaborative activity between the two subjects, such as examining how wind energy production impacts electricity market prices and emissions, which shares the SDG learning objectives defined, would strengthen compliance with SDG 17.

The **cross-curricular** aspect is important because, as seen in the bibliographic review and in the analysis of the two case studies, integrating the SDGs into certain types of activities or assessment systems, such as those based on projects [29,31–33], is easier. For example, as illustrated in Figures 2 and 3, activities based on social impact projects are those that achieve the highest levels of alignment with the SDGs. However, subjects cannot always be adapted to this type of assessment or activity. Therefore, it is necessary to define a methodology for the integration of the SDGs into all the activities or assessments conducted.

Finally, to continue with this work and validate the proposed methodology, and after working one or two courses with the new learning objectives, a standardized SDG activity matrix must be recreated to verify if the degree of relationship between the course activities and the related SDGs has increased.

6. Conclusions

This paper presents a methodology for integrating the SDGs into undergraduate and graduate curricula based on the competency-based educational model. The methodology is intended to diagnose, in a straightforward and quantifiable manner, the extent of SDG implementation in a subject and, once assessed, to adjust the definition of learning outcomes to incorporate the SDGs across all the subject activities.

The main contribution of the proposed methodology is the use of an analysis tool based on fuzzy logic, obtaining standardized matrices to link competencies, activities, and the SDGs, facilitating quick and visual evaluation. This enables the subject to be evaluated initially for SDG integration and to be reassessed later to ascertain if the integration has been genuinely effective, i.e., transversal. Applying this methodology, the redefinition of learning outcomes and modification of activities for the complete incorporation of the SDGs into the curriculum can be achieved.

Nevertheless, the research is limited by its validation in only two European courses, which restricts the immediate generalizability of the findings to other educational contexts. Moreover, the application of this methodology requires that the competencies addressed in each activity have been correctly identified in the subject in advance.

As future directions, the authors propose applying and validating this methodology in other bachelor's and master's degrees across diverse disciplines—technical, social, and humanistic—which will allow us to verify its adaptability and scalability. Furthermore, working with the SDGs at the university level strengthens the training of conscious and committed professionals and fosters the transfer of knowledge and technology to companies, promoting more sustainable and innovative production models.

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Abbreviations

The following abbreviations are used in this manuscript:

AA1	Case Study Evaluation
AA2	Research Activity
AEC	Social Impact Project
AHP	Analytic Hierarchy Process
C1–C2	Self-Assessment Test
E1	Final Written Exam
EDS	Education for Sustainable Development
GC	General Competency
HEI	Higher-Education Institution
LO	Learning Outcome
PBL	Project-Based Learning
SC	Specific Competency
SDG	Sustainable Development Goal
STEM	Science, Technology, Engineering, and Mathematics
TC	Transversal Competency
UDIMA	Distance University of Madrid (Universidad a Distancia de Madrid)
UPV	Technical University of Valencia (Universidad Politécnica de Valencia)

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