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Embedding Sustainability Competences into Engineering Education. The Case of Informatics Engineering and Industrial Engineering Degree Programs at Spanish Universities

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Abstract: The incorporation of sustainability in universities finds the greatest barriers in the field of teaching. The curricula do not usually cover all dimensions of sustainability as most of the experiences are isolated and they do not reach all students. Within a larger study, an exploratory investigation has been carried out on how sustainability competences are being integrated into the programs of both Informatics Engineering and Industrial Engineering degrees of 25 Spanish universities. The main findings suggest that existing courses in the domain of the humanities and engineering projects, as well as the final degree project, are very appropriate areas for developing a holistic and reflective approach. Likewise, there is a lack of environmental issues in Informatics Engineering, and ethical issues do not usually appear in Industrial Engineering courses. In general, there is no systematic and strategic integration along the degree programs. However, inspiring practices have been identified to propose lines of action and a curriculum model to embed sustainability into engineering education coherently and effectively. In addition, some reflections on drivers, opportunities, and challenges to achieve it are presented.

Keywords: sustainability; engineering education; curriculum; strategic approach; holistic approach

1. Introduction

Over the last decades, it has been seen that neither the responses to global, social, and environmental challenges nor their implementation, are simple or evident in the complex framework of the current globalization. The problems are multi-causal and affect many different stakeholders, e.g., governments, companies, educational institutions, unions, and civil society. All these agents have different ways of intervening in the process, depending on their power, urgency and legitimacy, as well as their knowledge and capacity for action [1–3]. In particular, the technology and engineering sector, as a relevant manager of the interaction of human beings with their natural environment, plays a fundamental role in managing current tensions between economic and social development and environmental conservation [4,5].

Professional engineering institutions already include in their deontological codes the need to integrate sustainability criteria into practitioner activity [6]. Also, it is considered necessary to bear in mind not only the responsibility for the direct consequences of practitioner activity (environmental, social, psychological, economical, etc.) but also future responsibilities (forward-looking responsibilities). Assuming that it is impossible to have full certainty about the social impacts of technology in the future, this does not exempt practitioners and institutions from their responsibility to develop new technologies so that their impacts are desirable and lead to greater empowerment of people, instead of limiting it [7–9].

The report of the UNESCO Commission for the Ethics of Scientific Knowledge and Technology [10] on contributions to the 2030 Agenda concludes the need to find new institutional responses to the social changes induced by the development of scientific and technological knowledge. The most relevant issues include the inequality of access to the benefits of such developments and the tensions that are generated between public and private interests. Given the challenges identified, they proposed the development of more open models for access and decision-making related to scientific and technological knowledge, the review and development of agreed ethical standards, as well as the promotion of the ethical training of scientists and professionals to integrate these standards into the daily functioning of scientific, technological institutions, organizations, and companies.

For all these reasons, the good engineering practitioner must be fully aware of what is happening in society and have the necessary skills to face the social issues of technological development [11]. Among these skills, holistic and systemic vision and a proactive attitude to identify problems and effects in the mid and long-term become essential as well as the ability to identify and include external stakeholders into the decision-making process regarding the development of new technologies and infrastructure, with the purpose to promote ethical and responsible management for the organizations in which they carry out their professional activity [8,12–19].

The training of engineering professionals entails considering the role of Higher Education Institutions to face the challenges of sustainability and their commitment to Education for Sustainable Development (hereafter ESD). The responsibility of universities to address these challenges is recognized from many different fields, as reflected in more than thirty international declarations, letters, or initiatives that have been approved, disseminated, and signed by more than 1400 universities in the last three decades [20–23]. This responsibility affects its triple mission—education, research, and knowledge transfer—but also appeals to the universities themselves to assume, in their management, the criteria and values of sustainable development [24–27].

Many reports and studies on the incorporation of sustainability in the university reflect that the greatest barriers and difficulties of change are in the field of teaching [18,28–33]. It is still far from achieving an orientation of the university curricula towards sustainable development. Academic programs do not usually cover all their dimensions, and there are few examples of large-scale change in them. In addition, most of the experiences are isolated and with a low incidence in the development of education plans at a general level, not reaching all students [18,30,34–39].

This situation reflects the relevance of developing research that will serve as a reference for the effective and systematic integration of sustainability into university curricula, and, in particular, into engineering degrees [40]. The complexity of these issues implies that the chosen teaching models must provide a holistic and systemic vision, spaces for reflection, and tools to address wicked problems incorporating "non-technical" thinking and criteria.

Therefore, this article contributes to this process by describing the research carried out on the integration of sustainability into engineering degrees in the Spanish university system. The curricula of both Industrial Engineering and Informatics Engineering degrees of 25 Spanish universities have been analyzed. Special attention to whether sustainability is embedded holistically and systematically throughout the curriculum has been paid, and some good practices have been identified.

The study is part of broader research on the integration of sustainability competences, corporate social responsibility, and professional ethics in engineering degrees. This framework research included the analysis of teaching interventions along several years and a reflection process to provide proposals from different perspectives: curriculum, teaching practice, and institutional support [41].

The outline of the article is as follows: Section 2 summarizes the conceptual framework based on the literature review of the competences that are considered necessary for future engineering practitioners to face the challenges of sustainable development. In Section 3, some proposals for embedding these skills in university programs are reviewed and described. Section 4 briefly describes the academic context of engineering degrees in Spain. Next, Section 5 presents the methodology designed for this research and Section 6 explains the main results obtained. The practical implications of these findings are discussed in Section 7. In the Section 8, the main conclusions and final reflections are presented.

2. Sustainability Competences for Engineering Education

In the framework of the 2nd International Conference on Engineering Education in Sustainable Development in 2004, the so-called Declaration of Barcelona [14] was published to emphasize the importance of sustainable development in technological training and encourage higher education in engineering to integrate the objectives of the ESD in their actions. In that manifesto, the capacities that were considered necessary for engineering professionals to face the challenges of sustainable development were specified (Table 1). These competences are consistent with the approaches and characteristics of the competences that are considered basic for ESD in general [42–47].

Table 1. Declaration of Barcelona on competences for engineering practitioners [14].

Today's Engineers Must be Able to
• ***Understandhow their work interacts with society and the environment***, locally and globally, in order to identify potential challenges, risks, and impacts.
• ***Understand the contribution of their work*** in different cultural, social, and political contexts and take those differences into account.
• ***Work in multidisciplinary teams*** in order to adapt current technology to the demands imposed by sustainable lifestyles, resource efficiency, pollution prevention, and waste management.
• ***Apply a holistic and systemic approach to solving problems*** and the ability to move beyond the tradition of breaking reality down into disconnected parts.
• ***Participate actively*** in the discussion and definition of economic, social, and technological policies to help redirect society towards more sustainable development.
• Apply professional knowledge according to deontological principles and universal *values and ethics*.
• ***Listen closely to the demands of citizens and other stakeholders*** and let them have a say in the development of new technologies and infrastructures.

Liebert [48] highlights the importance of knowing and understanding the relevant role of technology in today's world, which affects both the natural environment and society. He considers it is necessary to know the social processes related to technological development, as well as the legal frameworks that society defines to regulate its relationship and determine the responsibilities and obligations when damages occur. The role of technology in social development is sometimes ambiguous and sometimes problematic; it is a generator of problems, but it also has the potential to solve them, and it is essential to make this potential visible to students.

Since education time at the university is limited and there is a great diversity of technological fields, some authors consider that the most appropriate option is to provide students with the fundamentals, criteria, principles, and values of the sustainability paradigm. The main goal is that they choose solutions that balance environmental, economic, and social issues by analyzing them from a systemic approach. In addition, as already mentioned in the introduction, students must learn to think about long-term processes, with the capacity to anticipate, considering that not everything can be completely controlled. Moreover, it is necessary to convey the complexity of the social context in which these processes are carried out, which will involve multidisciplinary frameworks of action, and, although it sounds disappointing, that there are no simple recipes for developing sustainable technologies [18,49,50].

From the perspective of social responsibility, Doorn and Kroesen [51] consider that the essential point on engineering education is to empower students to contribute positively to the social, economic and legal context of their professional activity, providing capacities to address the dilemmas derived from the unwanted effects of technology and ensure a positive impact of it on society. Students should develop a proactive attitude to critically analyze situations and act responsibly. Professional life is not simply an environment in which challenging technical problems are solved but also a place where you have to judge, value, and make decisions that affect concerns, needs, interests, and values of many different sectors of society [48].

In that way, one of the trends identified in a recent study of the Massachusetts Institute of Technology on engineering education was the orientation of the curriculum towards the design of projects with a relevant social implication [37].

In engineering studies, there is a risk that ethical or social component decision-making will be addressed in the same way as the resolution of technical problems, being necessary training in other ways of rationality [15,52]. It is essential that future engineers are trained to include other stakeholders and participate in reflection and decision-making processes on technological projects and/or policies [7,19,53–57]. But social responsibility is not restricted to individuals and also affects organizations where their activity takes place. Therefore, it is also important that students not only know and understand the general principles of Corporate Social Responsibility (CSR) but also what are the relevant issues when the use, design, or development of technology is at the core of the company's activity [19,58–60].

All these competences mentioned are specified in various ways in the learning outcomes and criteria established by different engineering accreditation agencies [61–64]. Table 2 collects some of them.

Table 2. Learning outcomes established by engineering accreditation agencies. Selection of the authors.

Knowledge and understanding	An ability to analyze societal and environmental aspects of engineering activities. Such ability includes an understanding of the interactions that engineering has with the economic, health, safety, legal, and cultural aspects of society, the uncertainties in the prediction of such interactions; and the concepts of sustainable design and development and environmental stewardship [62].
Application	An ability to design solutions for complex, open-ended engineering problems and to design systems, components or processes that meet specified needs with appropriate attention to health and safety risks, applicable standards, and economic, environmental, cultural and societal considerations [62].
Ethics and values	An ability to recognize ethical and professional responsibilities in engineering situations and make informed judgments, which must consider the impact of engineering solutions in global, economic, environmental, and societal contexts [61].
Working with others	An ability to function effectively in national and international contexts, as a member or leader of a team, that may be composed of different disciplines and levels, and that may use virtual communication tools [64].

3. Embedding Sustainability Competences in Engineering Curricula

As seen in the previous section, there is no single list of competences. Each institution, each academic program, and each course must choose the strategy and competences that best suit their circumstances and objectives. But the point is not which competences are in the list, but rather how they are effectively reflected in the curriculum [1,65,66]. In this section, several factors that are considered important to effectively and coherently develop the development of sustainability competences in the university curriculum are reviewed.

The final report of the Decade of Education for Sustainable Development [29] recognizes that it is not enough to scale and replicate good teaching practices that have been identified, but that a strategic and systemic curricular change is necessary, proposing a whole institution approach that affects curricula, teaching methodologies, research, social engagement, internal management, and governance. This process carried out involving all actors and taking advantage of the reference for sustainable development is an opportunity for the transformation of the university itself [1,18,26,27,29]. However, it seems that this approach is still the exception rather than the rule, which justifies the interest of studying what the situation is with engineering degrees in Spain in relation to the integration of sustainability competences.

In a recent review of the literature on sustainability and engineering curricula, Thürer et al. [40] shows that the degree of change in the curricula ranges from new material on sustainability in an existing module, to a new module on sustainability in an existing program, to an entirely new program of study on sustainability.

But it is important to keep in mind that embedding sustainability into the curriculum does not mean introducing new content or new modules in the curricula, which in general are already very overloaded [18,29,67]. The change must involve the revision of teaching strategies enhancing the development of a critical and holistic vision, introducing interdisciplinary projects between different areas and courses, promoting problem-solving and decision-making that incorporates criteria of sustainability, ethical, and social responsibility [34,68,69]. To achieve sustainability, it is necessary to cover the competences through a combination of pedagogical approaches [70].

Additionally, the achievement of the learning outcomes defined in the curriculum must be assessed and reported, within the common framework of assessment of other competences and learning outcomes [35,36,66,70,71].

To be effective, it must be ensured that actions that involve the development of sustainability competences reach all students. Therefore, it is not about programming some optional activities or modules, but the curricula must include a significant number of compulsory courses where sustainability competences are embedded [29,35,36,68,72,73]. It must be done in a planned and systematic way, developing activities in different courses along the whole academic program, involving as many departments as possible. A coordinated, coherent, and incremental sequencing of the competences is necessary to guarantee deep and meaningful learning. In that way, the perception that sustainability competences are at the core of engineering education will be reinforced [50,72,74,75].

A relevant experience for embedding sustainability competences in university curricula in a systematic way is the design of "competency maps" for each degree, establishing a framework that enables integrating these competences holistically [75,76]. These maps are defined as a matrix, where the rows correspond to four basic sustainability competences and the columns at three levels of domain based on the Miller pyramid [77]: know, know-how, demonstrate and do. In each cell, the learning results for each competition and each level are explained.

According to a whole institution approach, it is proposed to connect the goals and learning activities of the academic program with the research and the current management of the campuses, incorporating students into the day-to-day of the university. This can be done by facilitating participation in decision-making related to actions to improve the campus sustainability, promoting reflections on the impacts of the research carried out at the university or reflections on the criteria for prioritizing its funding, fostering interdisciplinarity, and participation of external stakeholders, etc. [36,78,79].

For all these proposals to be possible, it would be necessary to develop flexible curricular models. Thus, be able to overcome the rigidity of the disciplinary structure and effectively integrate the development of generic competences and, particularly, sustainability competences [18,26,43,67,78,80].

To finish this section, the work done by Malmqvist et al. [81] defining a specific sustainable development standard for university education in engineering is presented. It is included in the set of other standards on several topics proposed by the CDIO™ Initiative, an innovative educational framework for producing the next generation of engineers that has been adopted by many universities throughout the world for their curricular planning and outcome-based assessment [82]. Table 3 describes this standard, which summarizes the lines explained in this section and can be a useful reference for embedding sustainability into engineering curricula.

Table 3. Proposal for a sustainable development standard within the framework of the CDIO standards [81].

Sustainable Development Standard
A program that identifies the ability to contribute to sustainable development as a key competence of its graduates. The program is rich with sustainability learning experiences, developing the knowledge, skills, and attitudes required to address these challenges. ***Description:*** The curriculum features sustainability learning experiences on a basic as well as advanced level. Sustainability is addressed both in dedicated course(s) and as integrated learning experiences included in disciplinary courses and projects. The curriculum offers opportunities for students to specialize in sustainable development on the advanced (master) level. ***Rationale:*** To address the issues of sustainability is a key challenge for mankind. Engineers need to understand the implications of technology on social, economic, and environmental sustainability factors, in order to develop appropriate technical solutions, as well as to collaborate with other actors in addressing socio-technical issues. **Evidence** may include, non-exclusively, one or more of the following: • Specific and detailed program learning outcomes addressing social, economic, and environmental sustainability • Specific course learning outcomes address social, economic. and environmental sustainability • Curriculum with dedicated sustainability courses, as well and integrated sustainability learning experiences • Documented progressive sustainability learning sequences across several courses and projects • Master programs offering opportunities to specialize in sustainability

4. Context Description

During the process of adapting Spanish university degrees to the European Higher Education Area (EHEA), the so-called *White Books* [83] were edited for the various degrees existing at that time. They analyzed the characteristics of the corresponding or related studies in Europe, labour insertion studies of graduates in recent years, professional profiles and competences, and proposed a curriculum structure, among other aspects.

Officially, some recommendations were established on the competences that should include degrees adapted to the EHEA. For example, the preamble of the Royal Decree 1393/2007, on the organization of official university education, states that "it must be taken into account that training in any professional activity should contribute to the knowledge and development of Human Rights, democratic principles, the principles of equality between men and women, of solidarity, of environmental protection, of universal accessibility and design for all, and of promoting the culture of peace" [84] (p. 5). Among the basic competences that all graduates must develop, Dublin descriptors [85] are included, including one directly related to sustainability competences: "have the ability to gather and interpret relevant data (usually within their field of study) to inform judgments that include reflection on relevant social, scientific or ethical issues" [84] (p. 24).

For the different areas of knowledge or professional sectors, different ministerial orders or resolutions of the Secretariat-General of Universities, published in the Official Bulletin of State, establish requirements or recommendations for the recognition of official degrees. They specified the competences that must be acquired throughout the studies. Related to engineering degrees, it is common to include several competences related to the ability to analyze and assess the economic, social and/or environmental impacts of the affected solutions, with the understanding of ethical and professional responsibility, or with consideration of socioeconomic, environmental, ethical or legal conditions in the development of engineering projects. Some examples are shown below in Table 4 of Section 5.1.

Table 4. Sustainability competences recommended by the official guidelines and the *key dimensions* associated with each of them. In bold, the keywords identified for selecting the different *key dimensions.*

Sustainability Competences	*Key Dimensions*			
	Ethic	**Environment**	**Social**	**Legal**
Every Degree [84]				
Ability to gather and interpret relevant data (usually within their field of study) to inform judgments that include a reflection on relevant **social**, scientific, or **ethical** issues	X		X	
Industrial Engineering Degrees [86]				
An ability to analyze and assess the **social** and **environmental** impact of technical solutions.		X	X	
A knowledge, understanding, and ability to apply the **legislation** necessary for the exercise of the Industrial Engineering profession.				X
Basic knowledge and application of **environmental** technologies and **sustainability**.		X		
Informatics Engineering Degrees [87]				
An ability to analyze and assess the **social** and **environmental** impacts of technical solutions, understanding the professional and **ethical** responsibilities of the Informatics Engineering practice.	X	X	X	
An ability to design, develop, select, and evaluate informatics applications and systems, ensuring their reliability, **security** and quality, in accordance with **ethical** principles and current **laws** and **regulations**.	X		X	X
An ability to design and evaluate person–computer interfaces that guarantee **accessibility** and usability to informatics systems, services, and applications.			X	
Ability to design appropriate solutions in one or more application domains using software engineering methods that integrate **ethical**, **social**, **legal**, and economic aspects.	X		X	X

Currently, every accredited university degree in Spain specifies and publishes the goals and the competences that must be acquired by its graduates. As well, every course of the curriculum publishes the so-called Learning Guide, a document that describes the course specifying, among other practical information, the competences, learning outcomes, syllabus and contents, teaching methodology, and assessment methods. These documents have been essential to carry out the study explained in the next sections.

5. Methodology

The main purpose of this study is to describe how the current degrees of both industrial engineering and informatics engineering are integrating sustainability competences in teaching, paying special attention to whether it is done holistically and systematically throughout the curriculum, and identifying good practices and reference models.

The methodology is based on benchmarking methods, used in the competitive analysis of companies and organizations, that focus on best practices and continuous improvement [88,89]. An external benchmarking typology has been chosen, comparing the behaviour of different universities that offer similar degrees. This approach has also been used for Sánchez Carracedo et al. [76]—with a lower range of universities—but it is different from other studies aimed at analyzing the performance of just one university in its different degrees (internal benchmarking) [90]. Moreover, a functional approach has been adopted, focusing the study on two specific aspects that have been considered critical: the holistic vision of sustainability competencies and its systematic inclusion in the curricula.

The study has been carried out exhaustively in the universities of the Community of Madrid (13 universities, 6 public and 7 private). To complete it, other Spanish universities have been selected that could contribute to the objectives of the study: technical universities, as specialists and referents in the field of engineering, and other universities attending to their involvement in the field of sustainability (such as their participation in the Higher Education Sustainability Initiative [91]). Finally, 27 degrees of computer engineering (hereafter, Informatics) and 28 degrees of industrial engineering (hereafter, Industrial) have been analyzed.

5.1. Data Collection

For the collection of data, the web pages on each of the selected universities and degrees have been reviewed, with the purpose of analyzing the presence of sustainability competences in the competences and objectives that define the degree, and especially the presence in the courses of the curriculum. To analyze the presence in each course, the information has been obtained from the mentioned *Learning Guides*.

A first pilot study was carried out, in which data from three universities were collected, and the possibility of extending the study to some foreign universities was studied, an option that was rejected due to the lack of homogeneity in the sources of information. From this pilot study, a small number of *key dimensions* were determined, attending their significance for the goal of the study and the facility to be clearly identified in the sources of information. They were the following:

- Ethics and professional responsibility
- Environmental
- Social
- Legal and regulatory

In this election, some competences relevant to ESD—critical reasoning, systemic thinking, multidisciplinary work or the economic dimension—have been ruled out. Every engineering degree in Spain includes mandatory courses on Economy, but the contents are not so much related to the inclusive economy, poverty, inequality, or employment, which would be the most significant topics for ESD; when they appear, they have been considered as social issues. The presence of critical reasoning skills is fundamentally related to technical aspects. The difficulty of distinguishing these nuances from the information provided by the *Learning Guides* has been the reason for not considering these competences as *key dimensions.* However, when they appear, they have been collected as relevant qualitative aspects.

As an example, Table 4 reflects the identifications made from the competences recommended in the official guidelines.

Specifically, information has been collected on:

- Which *key dimensions* are included in the degrees competences.
- Which *key dimensions* are included in the courses competences.
- Which *key dimensions*, and how many, are included in the syllabus of the courses.
- Methodological aspects that are considered of interest for the development of sustainability competences.
- Specific assessment methods for sustainability competences.
- Other data of the course: compulsory/elective, year, credits, faculty.

A thorough revision of the *Learning Guides* was carried out to collect all this information, using some keywords for each *key dimension*, but also taking advantage of the researchers' knowledge of the subjects for identifying their presence into the syllabuses and selecting inspiring practices. Figure 1 outlines the way the information has been collected.

			Key dimensions				Good practices		
Course	Type	Category	Ethic	Environ-mental	Social	Legal	Syllabus	Teaching	Assessment
	Compulsory Elective	ENV SAFE ECON HUM OTHER PROJ FDP	C : Only Competences S : Only Syllabus C + S : Both Competences & Syllabus 0 : Neither				Items of the syllabus related to *key dimensions* Appropriate or innovative teaching methodologies and assessment methods		

			Key dimensions				Good practices		
Course	Type	Category	Ethic	Environ-mental	Social	Legal	Syllabus	Teaching	Assessment
Practical cases in strategic management and entrepreneurship	Elective	ECON	C + S	C	C	0	**TEACHING:** All students (in groups of up to 3) will develop a real proposal of business plan in which to apply the contents of the subject, with special consideration to ethical aspect and responsibility of their own business idea **ASSESSMENT:** This business plan will be assessed by an oral presentation by the end of the course (30%), along with an essay (30%)		
Operative Systems Administration	Compulsory	OTHER	S	0	C + S	0	**SYLLABUS:** 1.5. Ethical code of the OS Administrator 11.4. Security and usability		

Figure 1. Outline of the methodology for collecting data for each course and some examples.

In addition, to facilitate the comparison and identification of relevant experiences and models, the courses have been classified into different categories. The categories defined, after the pilot study, are the following:

- **ENV:** *Environmental*. Courses directly related to the environmental dimension of sustainability, aimed at providing basic knowledge and applications of environmental technologies and sustainability. Some examples are "Environmental engineering", "Environment and sustainability", "Environmental management".
- **SAFE:** *Safety and Security*. Technical courses related to safety and/or security topics, as a matter with a relevant social impact in engineering, although with different nuances in Informatics or Industrial areas. In Industrial, they focus primarily on the prevention of occupational hazards, safety and industrial hygiene ("Quality and industrial safety", "Prevention of occupational hazards"). In Informatics, the field of security is linked to the protection of data and information and communications systems, with clear social, legal, or ethical implications in matters such as privacy or intellectual property ("Network security and cryptography", "Security computer and data protection").
- **ECON:** *Economy and Business*. Courses directly related to the knowledge of concepts of economy, organization and legal framework of the companies ("Fundamentals of economics and business," "Organization of technology companies.")
- **HUM:** *Humanities*. Non-technical courses related to different areas of the humanities or social sciences. There is a great thematic variety, which could be grouped into courses focused on professional ethics ("Professional Deontology"), in the field of technology and society ("Engineering, Industry, and Society"), legal issues ("Computer Law") or humanities and history ("History of Industrial Engineering"). In Informatics, many courses combine in their title several of the previous areas ("Ethics, Law, and Profession").
- **PROJ:** *Projects*. Include, here, the courses directly related to the development of skills to conceive, write, organize, plan, develop, and project management in the field of engineering. Examples: "Projects", "Project planning and management".

- **FDP**: *Final Degree Project*. All the degrees studied include in their curriculum the compulsory completion of a Final Degree Project (FDP). It is the last course that the student must pass to obtain the degree. At this point, students must demonstrate that they have acquired the necessary competences for their practitioner activity, including sustainability competences.
- **OTHER:** *Others*. Technical courses are included here that involve in their *Learning Guide* some sustainability competence. Examples: "Energy Engineering", "Robotics".

5.2. Interpretation and Data Analysis

Different variables have been defined to analyze the information and the data collected according to the objectives of this study. These variables are defined for each type of degree, obtaining results separately for the degrees of Industrial and Informatics so that differences and similarities between both areas can be identified.

To describe the presence of sustainability competences in the definition of the degrees' curricula, the following variables are used:

- Number of degrees that include each *key dimension* among their competences.

To analyze the holistically presence of sustainability competences in the degrees' courses, the following variables are analyzed:

- *Key dimensions* that a course includes into its syllabus.
- Number of degrees that include each *key dimension* in the syllabuses of their compulsory courses.
- Number of degrees that include each *key dimension* in the syllabuses of their elective courses.

To analyze the systematic presence of sustainability competences in the degrees' courses, the following variables are used:

- Number of compulsory courses that include some *key dimensions* in their syllabus.
- Number of *key dimensions* that are included in two or more courses throughout the curriculum.
- Number of degrees that include some *key dimensions* in each category.

Finally, to perform a more detailed and qualitative analysis, the data are interpreted separately for each category. This allows having a more detailed vision of how sustainability competences are being worked on according to the teaching context. In general, the following variables are studied for each category:

- Number of degrees that have courses (mandatory or optional) of that category.
- Number of courses that include some *key dimensions* among its competences and/or its syllabus.

In addition, for the identification of good practices, qualitative information is collected about teaching and assessment methodologies.

This study is framed in a broader research on the integration of sustainability competences in engineering education. Within this investigation, five focus groups—with both faculty and students—and four semi-structured interviews—to faculty involved in the design of curricula—have been carried out. Their analysis has contributed to contrast and to complete the results previously obtained from exploratory and experimental research [41].

5.3. Limitations

It is assumed that the study presented in this article has some limitations. In the first place, the analysis carried out provides information on a specific moment (in this case, the 2014–15 and 2015–16 courses), when the courses' syllabus is dynamic and changing. The main source of information has been the *Learning Guides* of the courses, which provide information that does not always correspond to the actual work in the classroom. It is not easy for nuances to be collected, such as the promotion of reflection or critical reasoning, the holistic approach to issues, specific activities, methodological innovations, etc.

As the study does not cover all Spanish universities, surely, there are relevant experiences that are not included in this study, and it is possible that not all good practices are identified in the universities studied.

However, assuming these limitations, it is considered that the breadth of the data collected, the detailed description of the process and the derived results, the review of atypical results, or the researchers' own reflection on possible biases, as well as the contrast with peers in different academic forums [92–95], support the validity of the study [96].

6. Results

As indicated in the previous section, the objective of this study is to describe how the current degrees of Industrial engineering and Informatics engineering are integrating sustainability competences into teaching, paying special attention to if it is done holistically and systematic throughout the curriculum, as well as identifying inspiring practices and reference models. The most relevant results in relation to these objectives are presented below.

First, great diversity in the way of integrating sustainability competences in the curricula has been observed. These differences occur between universities, the kind of degree (Industrial or Informatics), the category of courses, or the different *key dimensions* analyzed. There is not a unique model.

However, within this diversity, some common characteristics reflect the influence of the recommendations made by the administration during the process of adapting the curricula to the EHEA [84,90,91] and the guidelines proposed in the mentioned *White Books* [83]. For example, most of the sustainability competences defined for the degrees studied appear with equal or very similar wording to those given in the official reference documents (Table 4).

One of the most significant results is the general inconsistency between the inclusion of competences in the definition of the degree and its real presence in the syllabuses of the courses (Figure 2). At the degree level, all degrees of Informatics engineering include competences that cover every *key dimension*, but not every *key dimension* appears in the courses' syllabuses, the scarce presence of the environmental dimension is significant. In Industrial engineering, the situation is different, and the ethical dimension is not reflected in the syllabuses while it is considered in the competences; surprisingly, the rest of the dimensions appear more frequently in the syllabuses than in the competences.

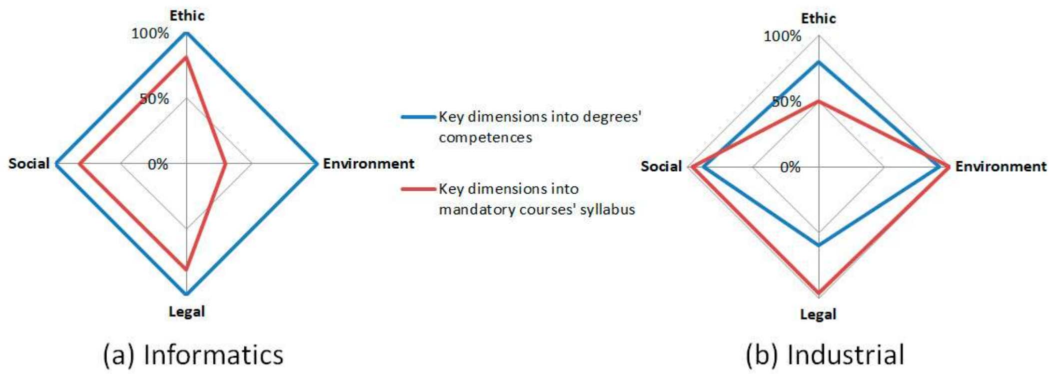

Figure 2. Comparison between the percentage of degrees that include sustainability competences in their definition and the percentage of degrees that include them in the syllabuses of compulsory courses. (**a**) Informatics engineering degrees; (**b**) Industrial engineering degrees.

This inconsistency also appears within the courses themselves. The courses that indicate that they develop sustainability competences that are not explicitly included in the syllabus are very frequent, especially in Informatics (Figure 3).

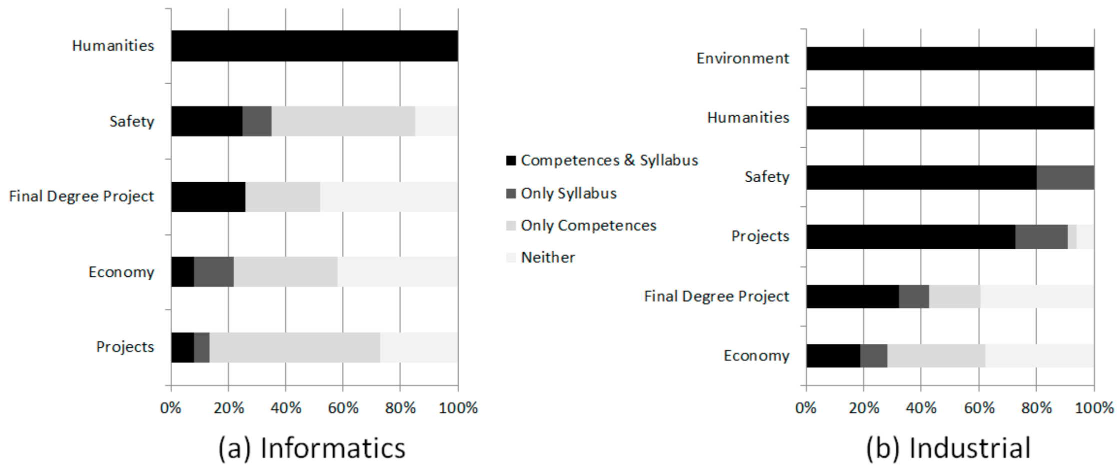

Figure 3. Percentages of compulsory courses (grouped by categories) which include sustainability competences among their competences and include some *key dimension* explicitly in their syllabuses. (**a**) Informatics engineering degrees; (**b**) Industrial engineering degrees.

6.1. Holistic Integration of Sustainability in Curricula

Regarding the holistic treatment of the different *key dimensions* studied, it is observed that the contexts in which the different dimensions are most frequently worked together are the courses of Humanities, Projects, and the Final Degree Project (FDP) (Figure 4).

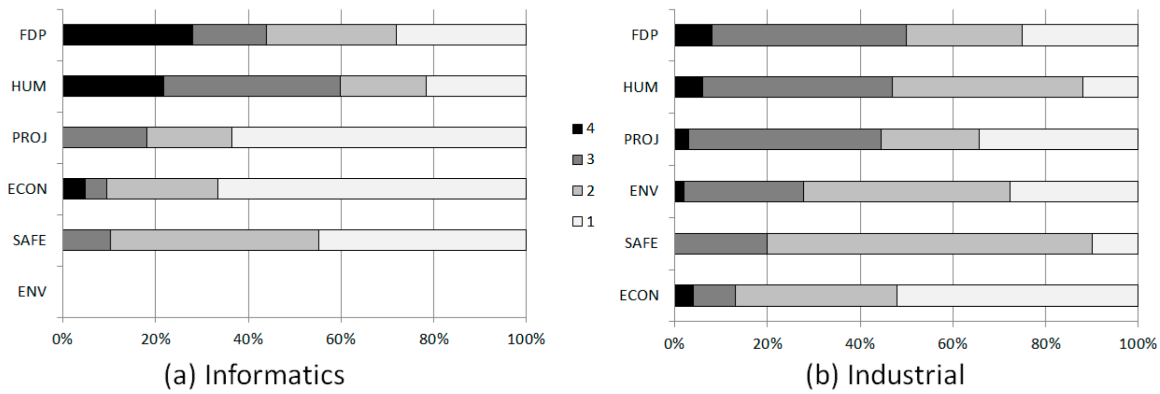

Figure 4. Number of *key dimensions* included in the courses' syllabus on each category. (**a**) Informatics engineering degrees; (**b**) Industrial engineering degrees.

The study shows that the Humanities courses are a facilitating and privileged context for a holistic approach to sustainability competences, due to the specific presence in the syllabus of topics related to social, environmental, ethical or legal issues, as well as for the teaching and evaluation methodologies applied. As are the courses of Projects and the Final Degree Project, as it is the natural place to work on the competences related to the design and development of applications and engineering services taking into account very different aspects (economic, safety, quality, environment, legality, ethics, etc.). However, sustainability topics are usually approached from a technical or regulatory perspective—mandatory reports of environmental impact or occupational safety—and rarely reflection, and interrelations between the different dimensions or a global vision are fostered.

6.2. Systematic Integration of Sustainability Competences in the Curricula

To study the systematic integration of sustainability competences throughout the curriculum, the number and type of courses that include them in their syllabuses have been counted. Two quite different models are observed in the Informatics and Industrial degrees. Figure 5 graphically reflects the quantitative results obtained.

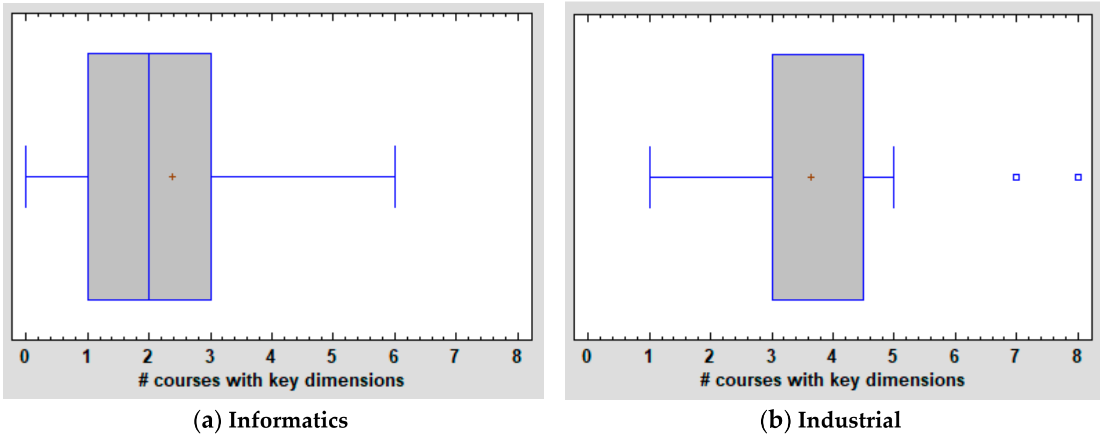

Figure 5. Box-Plot chart of the number of compulsory courses that explicitly include some *key dimensions* in its syllabus. (**a**) Informatics engineering degrees; (**b**) Industrial engineering degrees.

Assuming that the diversity observed is large (standard deviation of 1.5) and the existence of atypical cases (qualifications with seven or eight courses where some of the *key dimensions* are explicitly included in their syllabus), some general trends can be inferred.

It can be said that a "typical" degree in Informatics works on sustainability competences in one, two, or three courses: quartiles are $Q_1 = 1$, $Q_2 = 2$, and $Q_3 = 3$; in fact, two-thirds of the degrees studied has between one and three compulsory courses with *key dimensions* in their syllabus.

But Industrial Engineering degrees work on sustainability competences in three or four courses, on average. In this case, quartiles are $Q_1 = Q_2 = 3$, and $Q_3 = 4.5$; in fact, half of the degrees studied has three or four compulsory courses with *key dimensions* in their syllabus, and more than 75% has more than three.

By studying which categories of courses are those that incorporate sustainability competences in their syllabuses, different results are also obtained for Industrial and Informatics engineering degrees. Figure 6 graphically shows these differences.

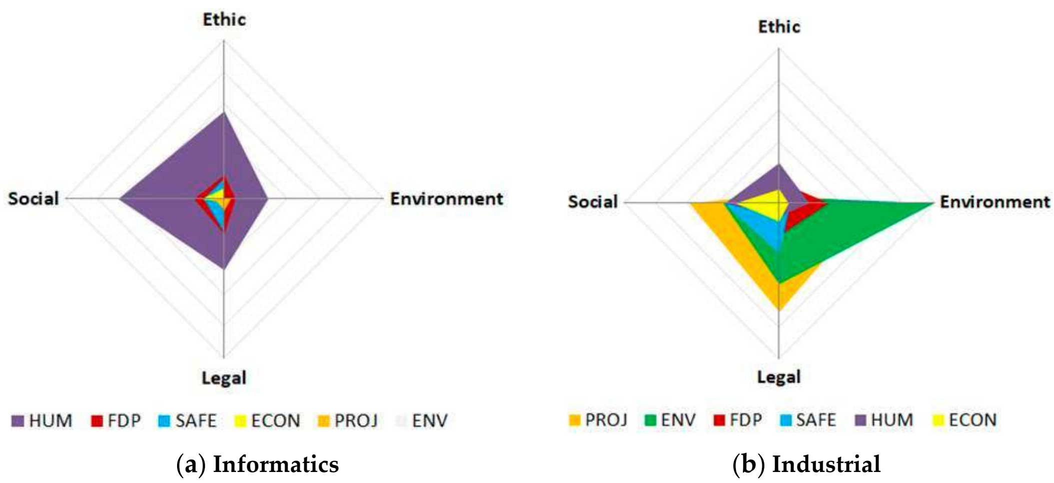

Figure 6. Percentage of courses of each category that include each *key dimension* in their syllabus. (**a**) Informatics engineering degrees; (**b**) Industrial engineering degrees.

In the case of Informatics, it is most likely that the development of sustainability competences is concentrated in a course of the category of Humanities. When the competences are included in a second course, it could be one of the categories of Safety, Economy, or Others. If they appear in more courses, they can be the FDP or Projects courses. Only social issues and sometimes ethical or legal issues are systematically worked (in two or more courses throughout the curriculum).

In Industrial, sustainability competences are developed mostly in courses of Environmental Technologies and Project courses. The other two categories more frequent are Economy and FPD, although there could also be different combinations with Humanities or Safety courses. On average, the environmental, social, and legal issues are systematically worked on in two or more courses throughout the curriculum.

It is observed that the Humanities courses are those that cover, in some cases, the deficit of the environmental dimension in Informatics and that of the ethical dimension in Industrial engineering degrees.

This situation reflects, again, the influence of official documents. The curriculum structure proposed in the respective *White Books* [83] included, as cross-cutting courses, a course of Ethics, Law, and Profession (in Informatics) and courses of Technical Projects and Environment (in the Industrial ones). Among those cross-cutting courses are also those related to Economy and Business Administration, present in every curriculum. Although it is not very frequent that topics of sustainability are included in the syllabuses of the courses in the category of Economy, some inspiring experiences are found (Section 6.3.4), and so these courses can be considered as an opportunity for embedding sustainability competences in a transversal way.

Table 5 collects examples of four degrees that reflect the situation described above and allows observing the specific courses that integrate sustainability competences in their respective curricula and which *key dimensions* are included explicitly in them.

Table 5. Inclusion of sustainability competences in the curriculum of four degrees. Elective courses are pointed by (*).

INFORMATICS (U. Deusto)			***Key Dimensions***			
Year	**Category**	**Courses**	**Ethic**	**Social**	**Legal**	**Environ-mental**
2nd	HUM	Elective Courses of Humanities	X	X		
	OTHER	Interaction and Multimedia		X		
3rd	OTHER	Knowledge Management	X		X	
	PROJ	Software Project Management			X	
4th	HUM	Civic and Professional Ethics	X	X	X	
	SAFE	Information Security		X	X	
	FDP	Final Degree Project			X	
Informatics (U. Valencia)			**Key dimensions**			
Year	**Category**	**Courses**	**Ethic**	**Social**	**Legal**	**Environ-mental**
1st	HUM	Engineering, Society and University	X	X		X
3rd	HUM	Ethics, Law and Profession	X	X	X	
Industrials (Barcelona TECH-ETSEIB)			**Key Dimensions**			
Year	**Category**	**Courses**	**Ethic**	**Social**	**Legal**	**Environ-mental**
2nd	ECON	Business and Economy		X		
	HUM	Technology and Society (*)		X		X
	HUM	Human Training for the Workplace (*)	X	X		
3rd	PROJ	Projects II		X	X	X
	ENV	Environmental Technology and Sustainability		X	X	X
	ENV	Building Sustainability (*)		X		X
4th	PROJ	Project Management		X	X	X
	PROJ	Project Management and Planning (*)		X		
	OTHER	Robotics at Engineering (*)	X	X		
	OTHER	Nuclear Engineering Fundamentals (*)				X
	FDP	Final Project Degree		X	X	X

Table 5. *Cont.*

Industrials (U. Basque Country, UPV-EHU)			Key Dimensions			
Year	**Category**	**Courses**	**Ethic**	**Social**	**Legal**	**Environ-mental**
4th	ENV	Environmental Technology		X	X	X
	PROJ	Engineering Projects		X	X	X
	ECON	Business Organization		X		
	OTHER	Nuclear Power Plants				X
	SAFE	Management, safety, hygiene and ergonomics (*)		X	X	
	ECON	Human Resources (*)		X		
	FDP	Final Degree Project		X	X	X

6.3. Results by Course Categories, Inspiring Experiences

During this study, some relevant experiences have been identified in every category of courses. They can be inspiring to address the development of sustainability competences in these types of courses. This allows being optimistic in stating that it is possible to work on sustainability competences in a systematic, balanced, and holistic way in the current academic framework. However, it is not frequent and there is much room for improvement.

Next, for each of the course categories, some results related to their presence in the curricula and their contribution to the development of sustainability competences are presented. This analysis will explain in more detail the results reflected in former Figure 6.

6.3.1. Courses of the *Humanities* Category

In this category are non-technical courses related to different areas of the humanities or social sciences. In these courses, there are significant differences between the degrees of Industrial and Informatics. In the first place, only a third of the Industrial degrees studied offer courses of this category (21% as compulsory), while 81% of the Informatics degrees studied do offer them (63% of them do so as compulsory courses).

In some universities, students must necessarily take a number of credits of either "humanities" or "values education", and to take them they can choose from a wide range of courses or activities. Another model is the offer of a "Diploma in Personal and Professional Skills" aimed at developing generic competences. Both frameworks are considered conducive to offer courses where sustainability competences could be addressed.

As seen in Section 6.1, the courses the category of Humanities are conducive to giving a holistic view of sustainability, observing that more than half of them work at least three of the *key dimensions* (Figure 4).

The syllabuses addressed are very diverse, but the most frequent thematic lines are: professional ethics and deontology; science, technology, and society; sustainable development or sustainability; corporate social responsibility and legislation related to environmental and occupational safety issues in Industrial, and related to privacy, intellectual property, crimes or cybercrime issues in Informatics.

A differential feature of these types of courses, compared to those of other categories, is that they incorporate active methodologies that promote reflection, debate, and student participation, both individually and as a team. The most frequent are case studies, ethical dilemmas, essays and presentations (individual or group), and debates, either open or with a defined structure. These activities are usually assessed and have an important weight in the final qualification, between 30% and 100%.

Another particular feature of these courses is the variety in the profile of the academic staff that teaches it. In most cases, it belongs to technical departments. Less frequently, professors of Law departments are observed—especially in Informatics—but there are no cases in which these courses are assigned to departments of humanities or social sciences.

6.3.2. Courses of the *Environmental* Category

Courses directly related to the environmental dimension of sustainability are considered in this category, aimed at providing basic knowledge and application of environmental technologies and sustainability.

All industrial engineering degrees (except three degrees of electronic engineering) include some compulsory courses of this category in their curricula. Also, half of them also offer optional courses in which the most frequent topic is that of renewable or alternative energy.

All these courses include environmental topics in both competences and syllabuses, but these are mainly technical. However, there are examples of courses that go beyond and promote a reflection on these topics and their interrelation with social or ethical issues.

The study has found two ways to introduce a reflection on environmental sustainability in the syllabuses. One of them is to include a specific chapter, usually the introduction to the course, which addresses the concepts of sustainability or sustainable development, environmental problems, and policies. The other is to introduce in each topic some points related to the analysis and qualitative assessment of the problems and impacts.

Concerning the other dimensions of sustainability, the most frequent is to address legal (50%) and social (36%) issues. Some examples of the latter are occupational hazards, health impacts, the impact of human activity on the environment, lifestyles and sustainability, sustainability policies, etc.

In general, the methodologies and evaluation methods proposed in these courses are not very innovative, but there are cases that foster critical reflection, awareness and an integral vision of sustainability, such as work on real cases, visits to companies and factories, project-based methods, or seminars on specific topics. Some inspiring experiences make explicit some sustainability criteria in the statement of the activities, such as "provide solutions that are committed to the quality of the facilities and to minimize their environmental impact".

6.3.3. Courses of the *Safety* Category

In all the Informatics degrees studied, there are courses of this category, although they are mandatory in just over half of them (56%). In the case of Industrial degrees, only 36% of them have specific courses in this category; however, these courses work more on sustainability competences and in a more coherent way than on the courses of Informatics degrees (Figure 3).

Social and legal issues are mainly addressed in the Industrial field (related to health, physical safety, and occupational hazards), and legal and ethical issues in the Informatics field (privacy and data protection). The focus of the courses in this category is fundamentally technical and, in general, there are no spaces for reflection.

In Industrial degrees, many courses in this category propose methodologies based on projects and work on real cases, calling for the development of a health or safety plan in a given context, and visits to companies or institutions are frequent.

6.3.4. Courses of the *Economy and Business* Category

All the degrees studied have compulsory courses of this category, both in Informatics and Industrial, since the knowledge of concepts of economy, organization, and legal framework of the companies is considered a competence for engineering education in Spain.

Regarding the inclusion of sustainability competences and their effective work in the courses, similar inconsistencies have been observed in the two areas. In fact, less than 25% specifically includes some of the *key dimensions* in the syllabus, while almost 50% declare some of them between the competences it should develop (Figure 3).

The most frequent way to introduce some sustainability topics is to address social issues (social welfare, unemployment and poverty, or social transformation capacity of technology). In some cases, they are linked to legal issues (related to occupational health and safety), to ethical issues (business ethics and CSR), or environmental topics (in sections such as "Social and environmental environment of the company" or "Environmental management and industrial safety"). Some degrees include courses (either compulsory or elective) dedicated exclusively to CSR.

Regarding teaching methodologies, there are interesting experiences of using active methodologies, such as case studies, debates, role-playing, specific workshops on ethics or CSR, and project-based methods, such as designing a business plan with special consideration to ethical issues and having responsibility for their own business idea.

6.3.5. Courses of the *Other* Category

When studying *Other* courses that include among their competences some *key dimensions* of sustainability, the study shows that most of them do not include anything related to them in the syllabus. However, in half of the degrees studied, at least one course has been identified to explicitly including some *key dimensions* in its syllabus. Depending on the scope of the degree, Informatics or Industrial, the courses that include them are different, as well as the *key dimensions* that are worked on. Figure 7 shows that the most frequent dimension is *ethics* in Informatics and *environmental* in Industrial.

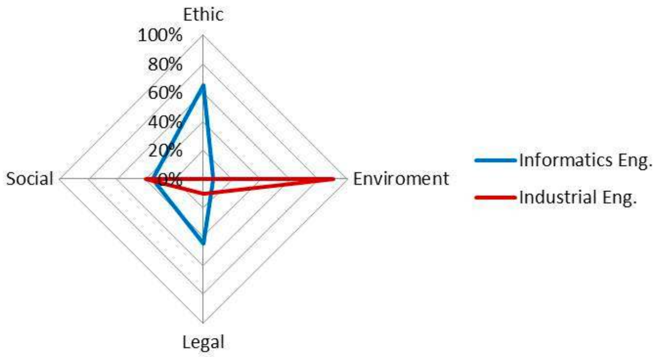

Figure 7. *Key dimensions* which are included explicitly in the syllabus of courses in the *Other* category.

In Industrial, environmental issues are fundamentally technical, related to the course's area of knowledge (for example, in "Industrial production systems", "Thermal installations", or "Industrial chemical analysis"). Social issues are related to safety and health risks in courses such as "Consumer chemicals".

In Informatics, the *key dimensions* are included in many different courses. The ethical dimension is included in modules of "Operating Systems", "Information Systems", "Software engineering", "Robotics"; legal issues, accessibility, and human factor are incorporated in courses such as "Person-machine interaction" or "Web technologies"; and environmental issues are incorporated as applications in modules on "Graphics".

6.3.6. Courses of the *Projects* Category

All the degrees studied, both in Industrial and Informatics, include some course of this category and in most cases they are mandatory. However, the way to integrate sustainability competences is very different to some degrees than to others. As it was seen in Figure 3, 90% of the Project courses of the Industrial degrees include some *key dimension* in their syllabus, while in Informatics, it does not reach 15%.

In Industrial degrees, the most common is the presence of specific topics on the study of environmental impact, studies of safety, hygiene, and occupational hazards, following current laws, regulations, and standards. Other social issues that are worked on in some project courses are accessibility, human resources management, user needs, or intellectual property.

In Informatics, the most frequent topics are related to legal issues (in a generic way), social issues, such as stakeholder management or security and, in a couple of cases, environmental topics related to prevention and waste management.

Concerning teaching methodologies, the majority works with practical cases, problems, essays, or presentations. Visits and seminars are also held, but only a few of them propose the development of a complete project throughout the course.

An interesting model is to include project courses in consecutive semesters, working specifically with different transversal competences (teamwork, communication, creativity, and sustainability). Another remarkable experience, that enhances interdisciplinarity, is to propose the completion of an industrial project throughout the semester, carried out by a group of students of different degrees in which each student will perform the assigned part related to their specialty.

Regarding the assessment, no cases have been found in which sustainability competences are specifically evaluated.

6.3.7. Courses of the *Final Degree Project* Category

The *Final Degree Project* (FDP) is mandatory in all the degrees studied. It has been observed that more than half of the degrees include sustainability competences among the competences to be developed in the FDP, but in the syllabus, only 43% of the degrees of Industrial degree studied, and 26% of those of Informatics degree include some *key dimension* explicitly (Figure 3). It was also mentioned above that the FDP is a favourable context for integrating the different *key dimensions* (Figure 4), mainly the inclusion of environmental, social, and legal issues in Industrial degrees, and legal, social, and ethical issues in those of Informatics.

In Industrial engineering degrees, the most frequent is to explicitly request either an environmental impact assessment of the project, a safety study, or a social impact assessment. Another option identified in some universities is to ask for a reflection on the social and environmental impacts of the project carried out, as well as on issues related to ethical and professional responsibility that could be related to it.

Regarding the assessment, the use of rubrics is the most frequent way. Some cases including some items related to sustainability competences have been identified, and some of them state the percentage of the corresponding grading.

A remarkable experience that can serve as a reference is that of the Informatics Engineering degree of the Barcelona Tech, where all the FDP must include in their final report a "Sustainability Report". Given the diverse nature of the FDP, this report cannot be defined precisely, so a set of guidelines is provided to help the student raise it. These orientations use the Socratic method, raising a series of questions—covering the three basic dimensions of sustainability in different phases of the product life cycle, as well as a risk analysis—which the student should reflect on. Furthermore, the student will assess the sustainability of their FDP based on a so-called "sustainability matrix". The sustainability report is evaluated and considered in the global grading of the FDP [97,98].

6.4. Contributions from the Focus Groups and Interviews

As explained in the section of methodology, it was considered appropriate to contrast and complete the results from the data analysis with the contributions of some focus groups and interviews with experts. Below are the most relevant contributions on how to integrate sustainability competences in engineering education from the perspective of the curriculum structure.

There is a generalized recognition of the complexity of both the subject—as sustainability is a complex concept—and the educational context, where the competence-based model is being assumed too slowly. Currently, most of the courses of the curriculum are focused on the contents and without interrelations between them. Some lines of action are proposed that have proven their effectiveness, such as the systematic monitoring of competency work in the curricula—through the existence of commissions and special staff responsible for competences training—and the commitment to more flexible curricula that facilitate interdisciplinary work in project-based learning contexts.

The opportunity represented by Project courses and FDP to embed sustainability competences into the curriculum has been highlighted. The greater flexibility of these courses allows experiencing new formats that promote the development of soft skills and interdisciplinary work. Sustainability issues being made explicit in the project guidelines is considered as a key point. When different courses are working with project-based methods, the approach of sustainability integration should be coordinated.

The relevant role of *Humanities* courses to integrate sustainability competences in the curricula is confirmed. Its value is highlighted as a teaching place where it is possible to go "beyond" the technical aspects. These courses also play a role as a reference for other academic staff interested in introducing sustainability competences in their courses. Two problematic issues were identified: the profile of the faculty that teaches these courses (engineering departments usually do not have people specialized in humanities), and the place they should occupy in the sequentially of the curriculum. Both issues raise, again, the need for systematic planning in the integration of competences in curricula, and the need for greater flexibility and interdisciplinary in the educational organization of the Spanish university.

There were also some contributions related to the importance of working sustainability in a transversal way in both the curriculum and extracurricular activities. The student group highlighted that they remember the topics of sustainability that were linked to projects or applications. Faculty also highlights the relevance of making sustainability visible in the technical contexts where it is relevant. In this line, it is proposed to take advantage of institutional initiatives of environmental management of the campus and to promote extracurricular activities (conferences, events, workshops, etc.) that foster social perspective, contact with real problems and interdisciplinary vision.

Given the complexity of the subject, it is essential a strong institutional commitment—that gives effective support to the faculty—provides organizational models that enhance planning and monitoring the integration of competences in the curricula, and promote greater flexibility of the curricula, fostering interdisciplinarity and contact with society in university education.

7. Discussion

From the previous results, based on what is already being done in some Spanish university degrees, some relevant factors are identified to effectively integrate sustainability competences in engineering education. First, proposals and reflections are presented regarding the structure of the curricula and the moments and ways that we consider most appropriate to work on sustainability competences. Afterward, reflections are offered on the possible steps to follow in order to implement better integration of sustainability in the curriculum, the importance of institutional support, and some levers and opportunities to achieve it.

7.1. Model for the Integration of Sustainability Competences in Engineering Curricula

For the integration of sustainability competences to be effective, it should be systematic and complementary throughout the curriculum, covering the different dimensions of sustainability. In a single course, it is not possible to develop all the competences at their different levels. On the other hand, the level of development of competences must also be adapted to the level of maturity and the abilities of the students.

A model for embedding sustainability competences into the current engineering curricula is presented below (Figure 8). It is based on three pillars:

- Including the principles of sustainability, professional ethics, and social responsibility in mandatory courses.
- Explicitly including such principles in project courses and, specifically, in capstone projects.
- Transversally embedding sustainability topics into appropriate courses of the curriculum.

This model is compatible with the current engineering curricula and the competences defined in them.

It is recommended for the fundamentals of sustainable development and social responsibility to be provided in the first semesters. In that way, students can address the rest of the courses considering them, facilitating the connections with other subjects of the curriculum.

This study establishes that the courses categorized as Humanities (Technology and Society, Professional Ethics, Legal and Professional Issues, etc.) are an effective way to introduce the basic concepts of sustainability, which also include ethical and social responsibility issues. These courses can provide a holistic and systemic vision of the implications of engineering practice, its impacts on society and the environment, as well as the ethical responsibilities involved.

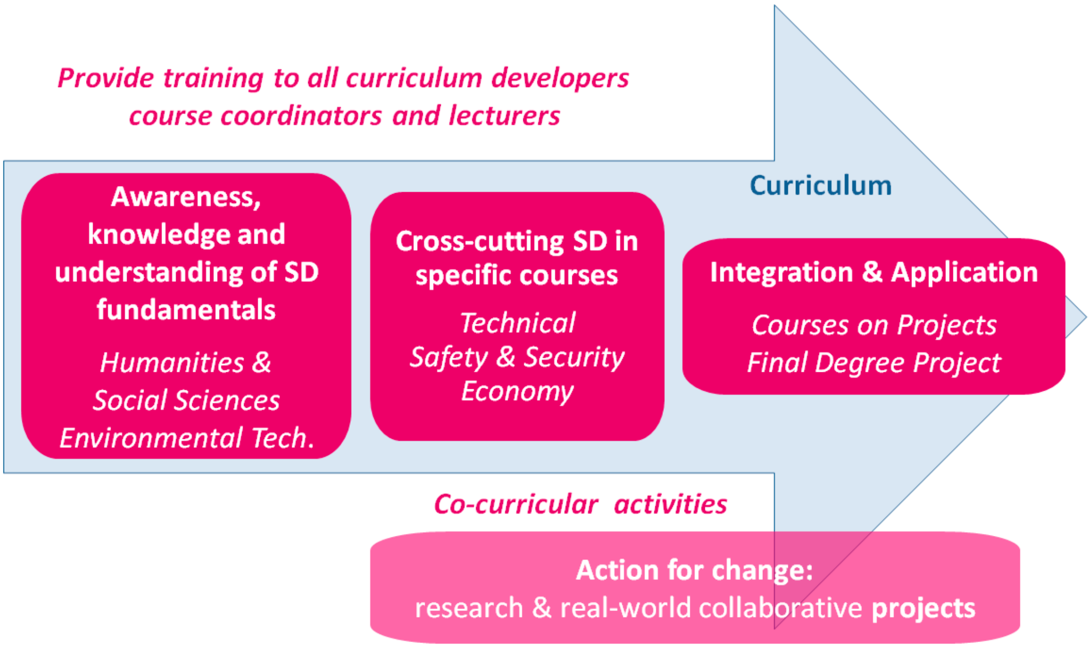

Figure 8. Model for the holistic and systematic integration of sustainability competences in engineering curricula (SD stands for Sustainable Development).

It is noted that in the curricula of Informatics engineering degrees, these types of courses are included in a high percentage, but they are not as frequent in the Industrial engineering degrees. But, in this case, the fundamentals of sustainability could be introduced in other courses that are present in the curriculum. *Environmental technology* courses may be very appropriate for this—in their introduction, for example—or in *Economics and Business* courses within the framework of CSR.

The introduction of the basic concepts of sustainability must also provide tools for reflection, analysis and critical reasoning that develop greater awareness, sensitivity, and proactivity in students when facing current challenges and their responsibility as future professionals. These skills must be developed throughout the curriculum.

The second pillar of the proposed model is the explicit integration of sustainability criteria in the courses of Projects and the FDP, which are part of the curricula of all engineering degrees. Their proximity to the resolution of real problems and the flexibility they have in terms of contents and methodologies, especially the FDP, make them very appropriate to integrate sustainability competences, especially in their most applied dimension. In addition, including sustainability criteria in this kind of course conveys the message that sustainability is intrinsic to the professional practice of engineering.

In these courses, it is important to go beyond the normative and the technical approaches, promoting an anticipatory reflection of impacts and risks, in the different dimensions (economic, social and environmental), taking into account all the possible groups affected and the entire life cycle.

As well, it is important to ask explicitly for an assessment of the final product in a manner that is consistent with professional ethics and current regulations, that minimizes risks and negative impacts, and that positive impacts are enhanced.

During this research, different ways to carry it out have been identified. Related to the Final Degree Project, some universities request explicitly that the FDP report include a report/reflection/assessment on the sustainability of the project carried out. From a curricular point of view, another interesting model is to include project courses in different semesters, working different generic competences and integrating all of them in the Final Degree Project. Some universities have gone further, reconfigured the teaching organization, and dedicating the last weeks of the semester to the realization of a project that integrates the competences developed in the rest of the courses of the said semester.

In order for students to address project courses with certain skills to include sustainability criteria, the third pillar of our model is necessary: the cross-cutting inclusion of sustainability competences in other courses of the curriculum. For this, it is necessary to identify the technical courses that are related to some relevant environmental, social, ethical or legal issues in the current context. It is important for the students to see that relationship at different times along the curriculum to reinforce the relevance of sustainability in engineering practice.

The challenge is to integrate them in a natural way, aligned with the current learning outcomes of the course. The goal should be expanding the scope of the course, promoting reflection, critical thinking and, when possible, a holistic vision, establishing connections between sustainability and the contents of the course itself. In Informatics and Industrial degrees, the study has shown appropriate courses such as computer security, environmental technologies, human-machine interaction, and renewable energy. In each degree, the most appropriate context must be identified, considering the topics of the course, the motivation of its professors, the research areas of the university, or other academic factors.

Similarly, it is recommended to work also in "non-technical" courses that are usually present in the curricula, such as modules related to Economics and Businessor Foreign Languages (English at the Spanish university). In the former, sustainability can be introduced from the perspective of CSR, comprehensive quality, or economic models such as circular economy or the economy of the common good. In the latter, the transversal nature of these courses, oriented towards communication competences, makes them appropriate to include sustainability issues for the development of said competences through activities such as debates or exhibitions.

One of the barriers encountered by faculty when including sustainability in their courses is the lack of methodological tools. In this sense, conferences by experts, case studies, ethical dilemmas, essays, presentations, debates, or class discussions are highly recommended.

During the focus group, both faculty and students highlighted the need for connection with real-world problems. An option is to offer extracurricular activities, such as seminars, projects, challenges, competitions, living labs, service-learning, that address some issues of social or environmental relevance, and that may have credit recognition. It is important that either the curricula—so overloaded in engineering degrees—or the academic organization, contemplate in some way to give place and time for these types of activities.

7.2. Levers, Opportunities, Proposals, and Challenges

The study carried out has not found any degree that meets all the above requirements, which indicates the difficulty of the task. However, the study has found inspiring experiences for every pillar proposed above, considering them separately. Therefore, the model is not utopian, and it could be real in the current academic context. The first proposal is to take advantage of the already existing initiatives.

In the study, some demands are identified, either from the universities themselves or from external agents. They can be used as either levers or opportunities for embedding sustainability competences in the curriculum effectively.

In the first place, the study shows that most of the degrees, and some of their courses, already include in their definitions and *Learning Guides* competences directly related to sustainability. In addition, the way in which they are included in the curricula follows in many cases the model provided by the *White Books,* edited to guide the process of adaptation to the EHEA and the recommendations of the official decrees [83,84,90,91]. This shows the importance of having sustainability present in the guidelines of educational institutions nationwide.

The incidence of national and international accreditation agencies of engineering degrees [61–64], and other professional institutions [12,15,81,82,99] in order to include sustainability competences in engineering education have also been identified. These external demands represent an opportunity to guide changes in the curricula and, following appropriate strategies, in the institutional culture itself. The periodic accreditation processes (either national or international) that are currently carried out at Spanish universities are also opportunities to evaluate how sustainability is already being included in engineering education. Additionally, it is an opportunity to propose and generate changes, as well as to make visible and recognize and value good practices.

But there exist other opportunities when considering a whole institution approach to embed sustainability in the curriculum. In each university, it will be necessary to identify which strategic initiatives allow aligning curricular sustainability. The options are the quality plans, university social responsibility strategies, sustainability plans, international accreditations, research projects oriented to social, and environmental challenges, etc. Currently, the Agenda 2030 and the initiatives around the Sustainable Development Goals represent also a great opportunity [26].

Following this strategic approach, it would be necessary to define the appropriate indicators to track the planned actions, evaluation of objectives, and accountability on them, enhancing their continuity and improvement. Some practices that have shown to be effective are the creation of committees of transversal competences (or of the figure of responsible for transversal competences), and the use of competences maps. The committees coordinate the inclusion of sustainability competences throughout the curriculum systematically and coherently. The competence maps assign the development of sustainability competences at different levels and dimensions to specific courses [75,76].

Regarding the model to integrate sustainability into the curriculum in a systematic way (Figure 8), the proposal is also to start from what is already being done, either in project courses, Humanities, or in a transversal way in technical courses. The study has found that almost every degree is already working sustainability competences into some courses. From this starting point, some references could be given to the faculty of other courses to introduce sustainability into their teaching. In this sense, it is important that the teaching training and the existence of work teams serve as references for faculty, students, and academic managers themselves. Again, it is proposed to take advantage of educational initiatives already underway (skills training, interdisciplinary work, initial teaching training, research training, etc.) to integrate into them the sustainability training for the academic staff.

Like many authors [18,30,39,44,100,101], it is considered essential that the integration of sustainability into the curriculum be carried out from a strategic perspective, combining bottom-up and top-down approaches, with a clear institutional commitment.

From the curriculum perspective, the main challenge identified is that of ensuring that sustainability competencies are not integrated into the curriculum on isolated occasions due to the individual initiatives of academic staff, but rather that they are developed consistently and systematically throughout.

From an institutional perspective, the challenge is the transformation of the university culture towards greater flexibility in the teaching organization to facilitate interdisciplinary and transdisciplinary, to foster a connection with society and real-problems, and thus overcome the rigidity of disciplinary structures. An instrument that has been effective is the existence of interdisciplinary meeting spaces, between academic and non-academic actors, which favour the exchange of experiences and promote transformation actions [102–105]. The challenges posed by sustainable development and their complexity can be a great opportunity to promote these spaces.

8. Conclusions

An exploratory research has been carried out to study how sustainability competencies are being integrated into the programs of both Industrial and Informatics engineering degrees in Spanish universities. Special attention has been paid to whether it is done holistically and systematically throughout the curriculum.

From a curriculum perspective, the research reveals some general characteristics. In informatics engineering degrees, the sustainability competencies are usually included in specific courses about social, ethical, and legal issues, and a significant lack of environmental issues has been observed. In Industrial engineering degrees, work on sustainability competencies is present in a greater variety of courses, especially those related to environmental technologies and projects, but ethical issues do not usually appear explicitly.

The main challenge identified is ensuring that sustainability competencies are not integrated into the curriculum on isolated occasions due to the individual initiatives of academic staff, but rather that they are developed consistently and systematically throughout.

The results of the research suggest that an appropriate and feasible model for holistically and systematically developing sustainability competencies within the engineering programs should be based on three pillars: (i) including the principles of sustainability in mandatory courses; (ii) explicitly including such principles in Project courses and Final Degree Project, and (iii) transversally embedding sustainability topics into appropriate courses along the curriculum.

This model is compatible with the current structures of the engineering curriculum and the competences defined in Spanish universities. It has been observed that existing courses in the field of humanities, projects, and FDP are very appropriate for developing a holistic and reflective approach. Additionally, courses in the area of economics and business, present in all degrees, are an opportunity to introduce sustainability competences.

The general proposal is not to introduce more complexity into the system, but to align actions with existing strategies, and to identify and take advantage of existing leverages and opportunities so as to address identified challenges. The study presented in this paper identifies as levers, the guidelines of educational institutions nationwide, the criteria and recommendations of international accreditation agencies of engineering degrees, and other professional institutions—that already include references to sustainability.

Some opportunities appear when considering a whole institution approach. Embedding sustainability in the curriculum should be aligned with the university social responsibility strategies, quality plans, sustainability plans, and research projects oriented to social and environmental challenges, etc. Currently, initiatives around the Sustainable Development Goals also represent a great opportunity.

Furthermore, an institutional commitment to promoting greater flexibility in how teaching is organized is considered a key factor. This flexibility should facilitate interdisciplinarity and connection with society, thereby overcoming the rigidity of the disciplinary structures.

Instruments such as faculty follow-up commissions, competence maps and multidisciplinary meeting spaces—for professors, students, and other internal and external stakeholders—have been identified as very useful for the university to train professionals and citizens committed to sustainable development.

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