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Implementation of Sustainability Indicators in Engineering Education Using a Combined Balanced Scorecard and Quality Function Deployment Approaches

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Abstract: One year and a half after the start of the COVID-19 pandemic, it became suitable to rethink the design of the engineering education systems to remain sustainable and resilient. The paper aims to identify the most important aspects of the system, as well as the most vulnerable ones and the extent to which the system meets the sustainability requirements of the society. The Balanced Scorecard approach is used to ensure that the system remains sustainable and resilient. The indicators to measure the aspects of this design are developed. A Quality Function Deployment approach is used to identify the extent to which a designed system satisfies the sustainability requirements of the society. The problem is formulated as an engineering design problem in which the customer requirements are presented using a sustainability Triple Bottom Line framework. The results indicate that a well-designed engineering education system is capable of addressing the majority of the 17 sustainable development goals (SDGs) identified by the United Nations. The most important aspect of this system is its commitment to quality assurance and continuous improvement. Such a system is a key player to achieve the SDGs, particularly those of economic growth, quality education, good health and wellbeing, and industry innovation.

Keywords: sustainability indicators; sustainable development goals; engineering education; quality function deployment; balanced scorecard

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1. Introduction

Sustainability has attracted the attention of engineering education over the past 30 years [1]. The early studies in this field can be traced back to the signature of the Talloires Declaration as an action plan for incorporating sustainability and environmental literacy in teaching, research, operations, and outreach at colleges and universities [2]. Initially, the declaration was signed by 12 founding members in 1990 and expanded over the years to include more than 500 signatories from 55 countries by 2016. These efforts required the development of the sustainability indicators as part of the performance management process. Some of these indicators date back to the early 1970s [3].

In the previous years, several authors concentrated on developing assessment tools and indicators of sustainability in higher education [4–6]. In particular, the study in [6] addressed, among other quality indicators, the resilience of the educational process and its preparedness for emergency situations as well as its impact on the sustainability of its environment.

In more recent studies, authors continued the same approach of addressing the assessment of sustainability in higher education [7–9]. In this area, the work carried out in the EDINSOST project in Spain [10–12] is commendable. The project has focused on designing instruments to evaluate sustainability in bachelor's and master's degrees in engineering, education, business administration and management, and environmental sciences [13]. Nevertheless, the authors of the present study could not find any attempts to integrate the sustainability indicators and the UN's SDGs [14] in the design and strategic planning of the higher education institutes. This may explain the serious challenges to the educational systems and their sustainability all over the world presented by the widespread COVID-19 pandemic.

Universities, in fact, have a long history of operating in unstable, disruptive, and unpredictable environments, particularly during wars, political upheavals, and financial crises. However, COVID-19 is unprecedented and its challenges to the education system and the whole society are huge. The pandemic came all of a sudden, and everyone was forced to deal with its consequences. Even the World Health Organization (WHO) took almost three months to recognize the criticalities of the infection and declare what was called, later on, "COVID-19 Pandemic" [15].

During this pandemic, engineering education faced several challenges to providing a substitution for hands-on experience, teamwork activities, and lab-based learning required by different engineering disciplines. Research was sharply reduced or completely stopped [16]. Financial challenges limited the ability of the universities to provide resources and faculty training for online teaching if they do not already have an online teaching component.

With a lot of resources used for hygienic on-campus measures during the first couple of months before closing the university premises in several countries, normal equipment and software acquisitions were halted. The spring semester in many cases was cut short and the final-year exams were prepared in a hurry. With very limited confidence in the online exams, a lot of preparations were put in place to carry out on-campus exams while ensuring social distancing and frequent sterilizations of the exam halls. This left the universities with very limited resources to support the staff working from home. In the ASEE survey, only 53% of the responding faculty members were given adequate resources [16]. As indicated in this survey and according to the authors' personal experience, the quick transition to online teaching affected faculty in different ways based on their previous experiences. Some faculty handled the conversion to online teaching smoothly, while others felt improvised and become very busy with the time-wasting activities to move courses online. Students faced several challenges to adapt themselves to the new learning experience and the new mode of communication while remaining at home burdened with familial interactions.

The students were missing guidance on career planning, as well as cues that come from body language, facial expressions, gestures, posture, and verbal and non-verbal interactions. Faculty are thinking that the ability of the students to master course material in an online setting is far less than that during the in-person contacts. The students lost internship opportunities and interactions with the local companies in their projects. Some students had to delay their graduation for at least one semester.

Low-income students suffered more with their limited ability to have fast Internet connections, high-performing computers, and audio and video equipment. The familial conditions of the students and their lack of suitable workplaces at home were additional burdens. In fact, this raised a legal perspective, since neither students nor the university staff are obliged to have the necessary equipment to enable the educational process outside the university premises [17].

The question about the success stories seems to be insignificant. One could not find such success stories anywhere. Some schools succeeded in managing the crisis with minimum losses, but nothing could compensate for the loss in delivering the same level of education as before the pandemic. The problems are coming from the nature of the engineering education which is based upon hands-on and lab-based experience as well as teamwork. Only in the schools that are designed to be resilient and committed to the sustainable development of their societies, faculty and students managed it and continued to serve their communities.

More than one year after the start of the COVID-19, it became important to integrate sustainability indicators in the strategic planning of the higher education institutes. In the present study, the Balanced Scorecard (BSC) approach is used to achieve this purpose. The indicators to measure the aspects of the engineering education system, in particular, are developed. In order to maximize the positive impacts of this system on society, the problem is formulated as an engineering design problem since engineering, as a discipline, has created very systematic processes for doing design work, whether the design of products, processes, systems, or services. Schunn [18] in his work on engineering educational design concluded that there are several mappings of engineering design processes into educational design processes and that this analogy is found to be very productive. In our work, an engineering design approach, in which the customer requirements are presented using a sustainability Triple Bottom Line (TBL) framework with three aspects: socio-cultural, environmental, and economic, is adopted. A Quality Function Deployment (QFD) approach is used to identify the extent to which the designed engineering education system satisfies the sustainability requirements of the society as the only customer of such a nonprofit system. Twenty interviews with faculty members in the authors' institute allowed the specification of the sustainability requirements of the society from an engineering education system, which span 12 out of the 17 SDGs for 2030 identified by the United Nations in 2015 [14].

The present paper aims to identify the most important aspects of the engineering education system, as well as the most vulnerable ones and the extent to which the system satisfies the sustainability requirements of society. The paper will start by discussing the BSC approach to identify the indicators of a successful engineering education process. This will be followed by analyzing the sustainability TBL of the society with three aspects: socio-cultural, environmental, and economic. The interactions between the two approaches will be discussed using the QFD method. In the results and discussions, two sets of results are presented. In the first set the customer requirements that span 12 out of the 17 SDGs are presented while, in the second set, the customer requirements are modified to address all of the 17 SDGs.

2. Materials and Methods

In order to achieve the target of the paper, a combined approach based on the Balanced Scorecard (BSC), Sustainability Triple Bottom Line (TBL), and Quality Function Deployment (QFD) is used. The BSC approach is used to ensure that the system remains sustainable and resilient. The QFD approach is used to identify the extent to which a designed system satisfies the sustainability requirements of society. The problem is formulated as an engineering design problem in which the customer requirements are presented using a sustainability TBL framework.

2.1. Balanced Scorecard Approach

Balanced Scorecard (BSC) was devised by Kaplan and Norton [19] for business applications in 1992. In 1993 they put it to work using measures across a more spread spectrum than businesses had done before. In the mid-1990s, academics and practitioners adopted the Kaplan and Norton work and modified the BSC design. In 1996, Kaplan and Norton [20] fully published their ideas. The BSC assists the organizations in the achievement of their strategic goals by providing an expanded range of performance indicators. The BSC includes four measurement perspectives: finance, customer, internal business process, and learning and growth [21].

Although the origin of the BSC method dates back to the early nineties of the previous century, it remained a popular tool in measuring the organizational performance not only in profit entities but also within nonprofit organizations. By nature, high educational institutions do not welcome the constraints required by robust management and cost control [22]. Nevertheless, many of these institutions have adopted BSC in their own strategic management system to measure performance [23,24]. Lassoued [25] and Fijałkowska and Oliveira [26], in 2018, worked on presenting a basis for a general BSC model for helping higher education managers for evaluating and managing the performance of their institutions with a research method based on a case study.

The four perspectives of BSC of engineering education institutes are the following:

1. Customer perspective for creating value and differentiation from the perspective of the customer.
2. Internal process perspective for various educational and academic processes to attain customer and shareholder satisfaction.
3. Innovation and learning perspective to create an environment that supports organizational change, innovation, and growth.
4. Financial perspective for gaining money, reducing costs, maximizing asset utilization, and minimizing risks.

Several key performance indicators that can be considered to measure improvements in each perspective are developed hereafter.

From the customer perspective, the organization should maintain a careful focus on customer needs and satisfaction. The customers of an engineering program include students and parents, faculty and staff, alumni, corporate members, and the local community. Table 1 shows the indicators used to measure the satisfaction of these customers.

Table 1. Indicators used to measure customer satisfaction in BSC.

Customer	Elements of Satisfaction	Performance Indicators
Students and parents	External ranking of the college	1. Absolute ranking of the college in academic ranking of world universities in engineering/technology and computer sciences.
	Accreditation and external review	2. Proportion of engineering programs in which there was an accreditation/external review to the total number of engineering programs in the institution over the past 6 years.
	Completion rate	3. Proportion of the undergraduate students who completed the program in the planned graduation time.
	Admission rate	4. Percentage increase in the number of students admitted to the program in one year.
	Students’ satisfaction	5. Percentage of graduating students who are very satisfied with the quality of their learning experience.
		6. Percent of students who are very satisfied with the numerous services offered by the program (restaurants, transportation, sports facilities, etc.).
		7. Percent of students who are very satisfied with the advising system.
	Students’ employability	8. Percent of graduates who within 6 months of graduation are employed or enrolled in graduate studies.
Faculty and staff	Salary growth	9. Average percentage salary growth of faculty and staff over one year.
	Faculty and staff satisfaction	10. Percent of faculty and staff who are very satisfied with the work environment.
	Professional growth	11. Percent of faculty and staff promoted in one year.
	Retention rate	12. Percent of faculty and staff who left the institute for reasons other than age limit in one year.
	Recruitment	13. Percentage of newly recruited faculty and staff in one year.

Table 1. *Cont.*

Customer	Elements of Satisfaction	Performance Indicators
Alumni	Graduate studies	14. Percent of college alumni enrolled in graduate study programs in the college of total students enrolled in graduate studies programs.
	Community services	15. Percent of alumni who participated in community services activities in one year to the total number of participants.
	Surveys	16. Proportion of programs in which stakeholders are surveyed for the continuous improvement of the program.
	Market requirements	17. Proportion of programs in which graduates are surveyed for compatibility between market requirements and curricular goals.
	On-campus activities	18. Percent of on-campus activities with alumni participation to total number of activities.
Corporate	Employers' satisfaction	19. Percent of employers who are very satisfied or satisfied with the performance of the graduates in the work environment.
	Training	20. Percent increase in the number of corporate staff benefiting from training programs conducted by the college in one year.
	Grants and endowments	21. Percent increase in grants/endowments generated from industry in one year.
Local community	Community services	22. Proportion of full-time teaching and other staff actively engaged in community service activities in the past year.
		23. Proportion of alumni engaged in one or more community service activities in the past year.
		24. Ratio of the number of general public activities, workshops, and awareness campaigns carried out by the institution to those carried out by the world's best practicing ones.
		25. Percent of beneficiaries who are very satisfied with the community services provided by the college in one year.
	Business creation	26. Percent increase in the number of companies created by the university students and employees over one year.
		27. Proportion of graduates establishing their own business to the total number of graduates in five years after the graduation.
	Community-oriented research	28. Percent of research activities linked to community development to the total number of research activities.
	Green university initiatives	29. Percent increase in university environmental activities/initiatives over one year.

The internal processes perspective is about the activities and processes that the system under consideration must do internally to create and deliver the required customer satisfaction values efficiently and effectively. This perspective includes continuous improvement, quality assurance, cost-efficiency, real-world exposure, and uniqueness. Table 2 elucidates the indicators used to measure the efficiency and effectiveness of the internal educational processes.

Table 2. Indicators used to measure efficiency and effectiveness of internal processes in BSC.

Elements of Internal Processes	Measures of Excellence	Performance Indicators
Continuous improvement	Student outcomes	30. Proportion of improved student outcomes to the total number of student outcomes under consideration in the last assessment and improvement cycle.
	Course delivery	31. Proportion of courses modified in content, teaching approaches, or assessment to the total number of core courses in the curriculum in the last assessment and improvement cycle.
	Research output	32. Percent increase in the number of publications in peer-reviewed journals per faculty member.
Quality assurance	Industrial advisory board	33. Proportion of programs in which the feedback of an industrial advisory board is included in the evaluation of the program.
	Exit exams	34. Proportion of programs in which the student competency evaluation/exit exam is carried out regularly.
	Professional exams	35. Percentage of students or graduates who were successful in the professional and/or national examinations.
	Quality audits	36. Proportion of programs for which an external administrative quality audit was carried out in the previous 5 years.
	Performance indicators	37. Percentage of the performance indicators of the operational plan objectives of the program that achieved the targeted annual level to the total number of indicators targeted for these objectives in the same year.
Cost efficiency	Faculty to student ratio	38. Percentage increase in the faculty to student ratio over the past 5 years.
Real-world exposure	Internship	39. Proportion of programs in which industrial training/internship is mandatory.
		40. Percent of on-site training supervisors who are very satisfied with students' internship/coop experience.
	Site/field visits	41. Number of site/field visits per student per year.
Graduate studies	Postgraduate programs	42. Proportion of departments in which specialized PhD and MS programs are offered.
Gender Equity	Female students	43. Percent of female students to the total number of students in the institution
	Female faculty	44. Percent of female faculty to the total number of faculty in the institution
Enhancing diversity and equality	Diversity	45. Percent of expatriated faculty and staff to the total number of faculty members in the institute
		46. Percent of expatriated students to the total number of students in the institute
	Equality	47. Ratio of average salaries of expatriated faculty and staff to the average salary in the institution.

The innovation and learning perspective is concerning the faculty and staff professional growth, incorporating technology into teaching, innovation in teaching, curriculum development/innovation, industrial partnership, international cooperation with distinguished universities, and resources management. Table 3 illustrates the indicators used to measure the innovation and learning perspective.

Table 3. Indicators used to measure the innovation and learning perspective in BSC.

Elements of Innovation and Learning	Measures of Excellence	Performance Indicators
Professional growth	Faculty	48. Proportion of teaching staff participating in the professional development activities in the past year.
		49. Proportion of faculty members who had more than one refereed publication in the past year.
		50. Percentage increase in the average number of refereed and/or published research papers per each faculty member during the year.
		51. Percentage increase in the average number of citations in refereed journals from published research per faculty member in one year.
		52. Percentage increase in the number of papers or reports presented at academic conferences during the past year per full-time equivalent faculty member.
	Staff	53. Proportion of technical staff participating in the professional development activities in the past year.
		54. Proportion of the administrative staff participating in professional development activities in the past year.
Incorporating technology in teaching	Courses	55. Percentage increase in the number of courses incorporating new technology (such as learning management systems, augmented reality, virtual reality, virtual labs, and online teaching) to the total number of core courses in the curriculum in the last 5 years.
Innovation in teaching	Courses	56. Percentage increase in the number of courses that use modern learning approaches (such as active cooperative learning and project-based and problem-based learning) to the total number of core courses in the curriculum in the last 5 years.
	Faculty	57. Proportion of teaching staff participating in teaching workshops in the past year.
	Research	58. Proportion of refereed publications in the field of engineering education to the total number of refereed publications in the past year.
Curriculum development and innovation	Curriculum revisions	59. Proportion of engineering programs in which there was an independent verification of the curriculum and the standards of student achievement to the total number of engineering programs in the institution in the past 6 years.
	Curriculum updates	60. Percentage of courses added/removed/updated to the total number of courses in the curriculum in the past 6 years.
Industrial partnerships	Companies	61. Percent increase in number of industrial agreements, MOU, partnerships, cooperation, student training, joint research, and so on in one year.
International cooperation	Universities	62. Percent increase in the number of international agreements, MOU, partnerships, cooperation, student exchange, joint research, and so on in one year.
Resource management	Strategic initiatives	63. Proportion of introduced or modified strategic initiatives carried out in the last strategic plan revision, in order to benefit from opportunities and/or mitigate risks, to the total number of strategic initiatives of the plan.
	Learning resources	64. Percent of beneficiaries who are very satisfied with the adequacy and diversity of learning resources (e.g., library, online resources, references, journals, and databases).

The financial perspective is focused on ensuring return on investments and managing the major risks involved in the business. Objectives can be achieved by meeting the needs of all players involved in the business, such as shareholders, customers, and suppliers. For a higher education institute, this can be achieved through gaining money, improving efficiency, improving asset utilization, minimizing risks, and achieving success and growth. Table 4 points out the indicators used to measure the financial perspective.

Table 4. Indicators used to measure the financial perspective in BSC.

Elements of Financial Perspective	Measures of Excellence	Performance Indicators
Gaining money	Student fees	65. Percentage increase in the number of fees paying students admitted to the program in one year.
	Funds and endowments	66. Percentage of self-generated funds/endowments from the total budget of the institution.
	Patents	67. Percentage increase in the number of registered national and international patents during the past year per full-time equivalent faculty member.
	Paid services	68. Percent of revenue from paid services of the total budget of the institution.
	Entrepreneurial activities	69. Percent of the university income from entrepreneurial activities of the total university budget.
Improving efficiency	Overall efficiency	70. Percentage increase in graduation to the enrollment rate in one year.
		71. Percent of instructional expenditures of the total expenditures of the institute in one year.
		72. Percent of self-generated funds of the total expenditure of the institute in one year.
Improving assets utilization	Assets productivity	73. Percent of the average time during which labs, workshops, and sports facilities are fully utilized.
	Utilization of library resources	74. Percent increase in the number of beneficiaries from library resources.
	Utilization of online resources	75. Percent increase in the number of beneficiaries from online resources.
	Utilization of sports facilities	76. Percent increase in the number of beneficiaries from the sports facilities.
	Utilization of lab facilities	77. Percent increase in the number of external beneficiaries from the laboratories (profit and nonprofit activities).
Minimizing risks	Online courses	78. Proportion of online courses to the total courses offered.
	Emergency plans	79. Percentage of emergency plans for which there has been an independent peer assessment in the previous year.
		80. Percentage of emergency plans for which drills have been carried out in the previous year.
	Reserve fund	81. Annual percent increase in emergency/contingency reserve fund.
Success and growth	Success	82. Percentage increase in graduation to enrollment ratio in one year.
	Growth	83. Percentage increase in the number of students admitted to the program in one year.

2.2. Sustainability Triple Bottom Line

While engineering education works to educate and train students with a sustainability perspective, it will give them a learning experience to undergo cognitive and behavioral changes to become development leaders. While doing so, it will have the following impacts on the sustainability of its society:

- Positive impact on the socio-cultural development of the society.
- Negative ecological footprint on the society.
- Positive impact on the economic sustainability of the society.

UNESCO defines education for sustainable development (ESD) as follows [27]:

> *"A learning process based on the ideals and principles that underlie sustainability and is concerned with all levels and types of learning to provide quality education and foster sustainable human development—learning to know, learning to be, learning to live together, learning to do and learning to transform oneself and society".*

Education for sustainable development should also be viewed as a comprehensive package of education in which key issues are found, including but not limited to university social responsibility, gender equality, and the protection of indigenous cultures. On the other hand, a sustainability-oriented curriculum in an engineering education system and its associated assessment framework [28] gives the students and future engineers a learning experience to undergo cognitive and behavioral changes and become development leaders in their societies. In addition, the sustainability-oriented research in these institutes is a strong tool to achieve industry innovation and infrastructure sustainable development goals [14]. This adds to the role of higher education, and engineering education, in particular, to infuse ethics and professionalism as well as health and safety issues.

In order to measure the socio-cultural impact, indicators 1–22 in Table 5 are used.

Table 5. Indicators used to measure the sustainability dimensions in the TBL approach.

Elements of TBL	Measures of Excellence	UN's SDGs	Sustainability Indicators
Socio-cultural impacts	Infusion of sustainability in curricula	SDG 4: quality education	1. Percentage of courses that address the sustainability objectives in the curriculum.
			2. Percentage of faculty working on sustainability research projects.
			3. Percentage of sustainability-related ISI publications and patents on sustainability issues of the total ISI publications and patents in one year.
			4. Percentage of senior projects that address one or more sustainability objectives.
	Ethics and professionalism in curricula	SDG 4: quality education	5. Percentage of courses that address ethics and professionalism in the curriculum.
	International cooperation and partnership	SDG 17: partnership	6. Ratio of the number of international agreements, MOU, partnerships, cooperation, student exchange, joint research, and so on in one year to those carried out by the world's best practicing institute in one year.

Table 5. *Cont.*

Elements of TBL	Measures of Excellence	UN's SDGs	Sustainability Indicators
	Sustainability-oriented research	SDG 9: industry, innovation and infrastructure	7. Percentage of MS and PhD theses that address one or more sustainability objectives.
			8. Percentage of sustainability-related research projects from the total number of projects funded by the institution in one year.
			9. Percentage of funds provided for sustainability-related research from the total research fund provided by the institution in one year.
			10. Proportion of faculty working on sustainability research.
			11. Proportion of sustainability-related ISI publications and patents on sustainability issues of the total ISI publications and patents in one year.
	Community engagement, philanthropy, and volunteerism	SDG 3: good health and wellbeing	12. Percentage of full-time teaching and other staff actively engaged in community service activities in one year.
			13. Percentage of alumni engaged in one or more community service activities in one year.
			14. Ratio of the number of general public activities, workshops, and awareness campaigns carried out by the institution to those carried out by the world's best practicing institute in one year.
	Heritage conservation and respect of cultural beliefs	SDG 11: sustainable cities and communities	15. Percentage of master's and doctoral theses dealing with an idea to preserve the heritage or archaeological sites.
			16. Percentage of credit hours in the curriculum allocated to cultural beliefs and practices of the society, such as religion, linguistics, history, and literature subjects.
	Health and safety	SDG 3: good health and wellbeing	17. Percentage of senior projects that address one of the health or safety issues.
	Diversity and equality	SDG 10: reduced inequality	18. Percent of expatriated faculty and staff to the total number of faculty in the institute.
			19. Percent of expatriated students to the total number of students in the institute.
			20. Ratio of average salaries of expatriated faculty and staff to the average salary in the institution.
	Gender equity	SDG 5: gender equity	21. Percent of female students to the total number of students in the institution.
			22. Percent of female faculty to the total number of students in the institution.

Table 5. *Cont.*

Elements of TBL	Measures of Excellence	UN's SDGs	Sustainability Indicators
Ecological footprint	Reducing energy consumption	SDG 7: affordable and clean energy	23. Inverse of the ratio of electricity consumption per student a year to the consumption in the world's best practicing institute.
	Reducing water consumption	SDG 6: clean water and sanitation	24. Inverse of the ratio of water consumption per student a year to the consumption in the world's best practicing institute.
	Waste management	SDG 12: responsible production and consumption	25. Inverse of the ratio of waste produced per student a year to its value in the world's best practicing institute.
			26. Percent of recycled waste of the total waste produced
	Minimizing CO_2 emissions	SDG 13: combatting climate change	27. Ratio of carbon emission per student a year to the same value in the world's best practicing institute.
	Clean and renewable energy	SDG 7: affordable and clean energy	28. Ratio of funded projects dealing with the renewable energy to all funded research projects in one year.
Economic impacts	Knowledge economy	SDG 9: industry, innovation and infrastructure	29. Ratio of industry-funded projects to all funded research projects in one year.
	Generation of business	SDG 8: economic growth	30. Proportion of graduates establishing their own business to the total number of graduates in five years after graduation.
	Enrichment of job market	SDG 8: economic growth	31. Percentage increase in the number of graduates from the program in one year.
	Local university expenditures	SDG 8: economic growth	32. Percent of the university local supplies of the total university budget.
			33. Percent of the external guests of the university-held conferences of the total number of conferences' attendees in one year.
	Economically autonomous universities	SDG 8: economic growth	34. Percent of self-generated funds of the total expenditure of the institute in one year.

Nowadays, there are a large number of contradictory signs which highlight our society's contribution to the collapse of the planet: an increasing environmental burden, massive imbalances in wealth, an ecological footprint that exceeds the carrying capacity of the earth, and so on [29].

The ecological footprints are the measure of the people's consumption of the resources of the planet. Some reports indicate that our current consumption rate is equivalent to 157% of the natural resources on the planet, which means that we either have a planet and a half to maintain our environmental footprint or reduce our consumption [30]. In order to understand how we can reduce our impact on the environment through change in behavior and lifestyle, we must determine the ecological footprint of each individual or institution by estimating the amount of energy and resources used.

An important issue in addressing sustainability in higher education is the ecological footprint of a student's progress from admission to graduation. While the educational system works to produce graduates knowledgeable about sustainability perspectives, the system is applied on the ground. An entity working to produce future sustainability leaders should lead by example and have a process that generates a minimal footprint while students undergo cognitive and behavioral shifts. Table 5 presents indicators

23–28 used to measure the ecological footprints of engineering education to achieve the society requirement.

A development-oriented government recognizes the importance of quality education, which is a driving force for sustainable development. With long-term visions, it strives hard to transform into a knowledge-based and sustainable economy [31]. It is recognized that the proportion of the population who has completed higher education affects economic development and society. Graduates take their experience and knowledge to future employers and become major players in the knowledge society/economy. Additionally, research activities in universities are linked to economic growth. O'Carroll et al. [32] point out the need to focus on the following three channels: (1) Developing human capital through the entry of graduates into the workforce; this can be measured through the graduation rate and the time taken for the student graduation. (2) Improving productivity through the contribution of university research to industrial research and development; this can be measured through industrial cooperation. (3) Involving graduates in the localized spillovers as innovators, entrepreneurs, and job creators; this can be measured by the number of self-employed graduates.

Table 5 explains indicators 29–34 used to measure the required economic impacts of engineering education to achieve the society requirements.

2.3. Quality Function Deployment

Quality Function Deployment (QFD) is a Total Quality Management tool for defining the customer's demands in the customer's own voice, prioritizing these demands, translating them into engineering requirements, and establishing targets for meeting these requirements. QFD was invented in Japan by Yoji Akao in 1966, first implemented in 1972 at Mitsubishi Corporation, introduced into the US in 1983, and has been adopted by a number of industries, including automobile and electronics, starting from 1986.

The matrix approach that characterizes QFD may be a major tool to trace plenty of requirements and relationships that drive design decisions during a new product or process development. It is a team-based system where the team members work closely with each other to provide accurate and useful evaluation information. This means that it is not only the voice of the customer, but also the voice of all departments of the company included in the design process [33]. In this context, the authors of the present work shared the process with different colleagues in the engineering departments.

Today, QFD implementation goes beyond designing products or services to extend to any planning process where the team decides to systematically prioritize potential responses to a particular set of goals.

Few research studies have combined BSC and QFD for different purposes. Doror and Barad [34] have applied them to check the performance of an entire company. Sirin et al. [35] applied them in pavement management. This combination was also applied for the attainment of an effective performance management system through the active ways of assessing employees' performance to promote stakeholders' satisfaction, employees' engagement, and continuous improvement [35]. Other researchers have also combined BSC and HOQ approaches for strategic planning in educational institutes [36,37].

In the present study, QFD is used to develop the appropriate qualities of the educational system represented in the BSC of engineering education institutions to achieve society's requirements for sustainability.

Although QFD may include up to four phases, each with its benefits, a design team may focus much of its efforts on the first House of Quality (HOQ). Our work focused on using the HOQ in which the following steps are carried out.

- Step 1: Identify the customer requirements/needs (WHATs), also called the voice of the customer (VOC), which are represented by the sustainability requirements of the society from an engineering education institute. Based on the work presented in [6] and the faculty interviews a set of 28 customer requirements were specified. The interviews were carried out with twenty faculty members and were face-to-face in their offices during the first week of April 2020. The purpose was to identify the most relevant customer requirements from an engineering education system. Based on the previous work of the authors in [6], the interviewees were asked to allocate a value between 0 and 7 to a set of proposed requirements to indicate their relevance and did not seek to generalize. The sample included professors (8), associate professors (7), assistant professors (4), and lecturers (1) from aerospace, chemical, civil, electrical, industrial, mechanical, and mining engineering departments. Table 6 represents the average and the standard deviation of the responses; ordered by the highest average. Due to the limited size of the sample under consideration and the fact that all interviewees are faculty members, an alternative approach, described in step 4, was used to prioritize those customer requirements with high averages and low standard deviation values.

Table 6. Results of the faculty interviews.

Customer Requirements/Needs	Average (0–7)	Standard Deviation
Addressing health, safety, and wellbeing	6.05	1.69
Addressing ethics and professionalism in the curricula	5.95	1.77
Reducing energy consumption	5.82	2.21
Addressing sustainability in curricula	5.68	1.77
Waste management	5.68	1.89
Reducing water consumption	5.55	2.19
Generation of business	5.48	1.87
Enrichment of job market	5.45	1.83
Enhancing knowledge-based economy	5.43	1.94
Minimizing CO_2 emissions	5.41	2.23
Clean and renewable energy research	5.38	2.28
Sustainability-oriented research	5.14	2.28
Community engagement, philanthropy and volunteerism	4.95	2.31
Improving life on land	4.90	2.29
Enhancing international cooperation and partnership	4.86	1.98
Heritage conservation and respect of cultural beliefs	4.76	2.62
Economically autonomous universities	4.67	2.51
Local university expenditures	4.62	2.10
Enhancing diversity and equality	4.59	2.35
Initiatives to reduce hunger	3.95	2.46
Poverty reduction research	3.86	2.60
Initiatives to reduce poverty	3.71	2.43
Enhancing gender equity	3.68	2.53
Life on land in curricula	3.50	2.54
Hunger reduction research	3.36	2.51
Improving life below water	3.00	2.49
Addressing peace and justice	2.90	1.95
Life below water in curricula	2.72	2.47

The reliability of the data is measured using Cronbach's alpha, which is the most widely used measure to assess the internal consistency of the question scales used for data collection [38]. Cronbach's alpha is used to assess how consistently multiple items in a survey, interview, or test assess the same category or characteristic. The reliability is considered acceptable if Cronbach's alpha is at 0.7 or more. High values of Cronbach's alpha shown in Table 7 suggest high internal consistency between items of each aspect of the sustainability TBL framework requirements. The results show that the reliability coefficient ranges from 0.902 to 0.938 and the used scale is reliable for this study.

Table 7. Cronbach's alpha values for the TBL aspects in collected data.

TBL Aspects	Cronbach's Alpha
Socio-culture requirement (14)	0.938
Environmental requirement (7)	0.902
Economic requirement (7)	0.920

- Step 2: Define the managerial characteristics of the educational process using the BSC of the institute (HOWs) to meet the WHATs.
- Step 3: Determine the relationships between the WHATs and HOWs. A value of ONE is assigned if a HOW (or a BSC element) can help in achieving a certain WHAT (i.e., a customer requirement or a sustainability TBL element); otherwise, a null value is assigned. This is a simplification from the original QFD where the relationships between WHATs and HOWs could be Strong, Medium, or Weak and are assigned a value of 9, 3, 1, or 0 (blank), respectively.
- Step 4: Benchmark the WHATs, by rating/prioritizing different customer or sustainability requirements. This is normally carried out using the pairwise comparison charts [39] with the multi-voting approach. The process used in the present research is explained later in this paper.
- Step 5: Use then the typical matrix multiplications to find the importance of each HOW element in meeting the customer requirements. The process requires several iterations to ensure that the elements in the HOWs are sufficient to address all the WHATs. In some cases, it may be necessary to add additional HOWs with their performance indicators, modify some performance indicators, and/or reformulate some WHATs and their indicators to be more specific to the designed system under consideration.
- Step 6: Repeat the same process in Step 5 horizontally to find the degree to which the designed system satisfies each WHAT element.
- Step 7: Define the initiatives and performance indicators for various BSC elements identified based on the WHAT–HOW relationship, the results of sustainability requirements, BSC elements, and trade-offs obtained between different HOWs.

2.4. Prioritizing Sustainability Requirements

As indicated in Step 4, it is required to prioritize the customer needs, or WHATs. These WHATs are very specific to the problem under consideration. In order to bypass this specificity, the authors first mapped these WHATs into the 17 SDGs for 2030 [14] identified by the United Nations in 2015 (Table 8). It became clear from this table that a well-designed engineering education system may be capable of addressing at least 12 out of the 17 SDGs.

Table 8. Customer requirements/needs and their mapping to SDGs.

TBL Aspects	Customer Requirements/Needs	Sustainable Development Goals
Socio-culture	Addressing sustainability in curricula	SDG4: quality education
	Addressing ethics and professionalism in the curricula	SDG4: quality education
	Enhancing international cooperation and partnership	SDG17: partnership
	Sustainability oriented research	SDG9: industry, innovation, and infrastructure
	Community engagement, philanthropy and volunteerism	SDG3: good health and wellbeing
	Heritage conservation and respect of cultural beliefs	SDG11: sustainable cities and communities
	Addressing health, safety, and wellbeing	SDG3: good health and wellbeing
	Enhancing diversity and equality	SDG10: reduced inequality

Table 8. *Cont.*

TBL Aspects	Customer Requirements/Needs	Sustainable Development Goals
	Enhancing gender equity	SDG5: gender equity
Environment	Reducing energy consumption	SDG7: affordable and clean energy
	Reducing water consumption	SDG6: clean water and sanitation
	Waste management	SDG12: responsible production and consumption
	Minimizing CO_2 emissions	SDG 13: combatting climate change
	Clean and renewable energy research	SDG7: affordable and clean energy
Economy	Enhancing knowledge-based economy	SDG9: industry, innovation, and infrastructure
	Generation of business	SDG8: economic growth
	Enrichment of job market	SDG8: economic growth
	Local university expenditures	SDG8: economic growth
	Economically autonomous universities	SDG8: economic growth

Yang et al. [40] presented the global experts' perspectives on SDGs and their relations with the ecosystem services. A total of 366 valid questionnaires were gathered from a total of 66 countries belonging to Asia, Europe, North America, Oceania, Latin America, the Caribbean, and Africa who participated in a survey to value the SDGs. Overall, 49% of the respondents had a doctoral degree, 46% master's degree, and 5% bachelor's degree. In the academic entitlements, professors were 24% of the respondents, and 20% were associate professors and half of them conducted academic research for more than fifteen years. Figure 1 illustrates the prioritized scores of seventeen SDGs yielded in this study.

Figure 1. Prioritized scores of seventeen SDGs on global scale [39].

Based on this study and the mapping of QFD WHATs into the 17 SDGs indicated in Table 8, the authors assigned different weights to the customer requirements (Table 9).

Table 9. Prioritizing and ordering the SDGs.

Order	Sustainability Development Goal	Prioritized Score
1	SDG2: zero hunger	78.7
2	SDG6: clean water and sanitation	77.0
3	SDG1: no poverty	76.1
4	SDG3: good health and wellbeing	73.2
5	SDG4: quality education	66.6
6	SDG 13: combatting climate change	66.3
7	SDG15: life on land	65.5
8	SDG14: life underwater	59.6
9	SDG7: affordable and clean energy	56.6
10	SDG16: peace and justice	54.6
11	SDG12: responsible production and consumption	53.7
12	SDG11: sustainable cities and communities	51.9
13	SDG10: reduced inequality	50.4
14	SDG5: gender equity	49.3
15	SDG8: economic growth	44.8
16	SDG9: industry, innovation, and infrastructure	36.0
17	SDG17: partnership	34.3

3. Results and Discussion

The results of applying the BSC-QFD approach to two sets of customer requirements are presented hereafter. In the first set, the customer requirements that span 12 out of the 17 SDGs are considered based on the faculty interviews. In the second set, customer requirements are modified to possibly address all of the 17 SDGs.

3.1. First Set of Results: Addressing 12 SDGs

Figure 2 shows the QFD chart under consideration, based on the previously stated assumptions and ranking the WHATs (or customer needs) out of 10.

The figure compares the importance of different BSC perspectives in addressing the sustainability requirements of society. The internal process perspective is the most important from this viewpoint with approximately 40% as compared with 26% for learning and growth, 22% for the customer perspective, and less than 13% for the financial perspective.

On the other hand, engineering education addresses the sustainability TBL requirements unequally with more concentration on the socio-cultural requirements (above 40%) and less concentration on environmental (25%) and economic (34%) ones. This is not surprising since education is a socio-cultural activity on its own. Although educational activities are expected to degrade the environment by its footprint, environmentally-friendly initiatives can compensate for this effect. In this area, it is important to address environmental challenges through innovative and relevant research [41] as well as minimizing water, energy, and carbon flow [42].

Figure 3 shows that the most important aspect of the engineering education system in addressing the sustainability requirements of the society is its commitment to continuous improvement and quality assurance (14%), followed by faculty and staff satisfaction (7.7%), international cooperation (7%), engagement with alumni (5.2%), and curriculum innovation (5.1%). On the contrary, the lowest important aspects are real-world exposure and incorporating technology in teaching (1.1%) followed by enhancing diversity and equality (slightly above 1.1%). Although the last elements are important to have a quality engineering education, their impact on the sustainability of society is minimal.

Sustainability requirements (customer needs) \ BSC perspectives (design parameters)		Weight	Customer perspective					Internal process perspective							Learning and growth perspective							Financial perspective					Sum (score)	Relative importance of sustainability requirements satisfied by BSC perspectives (%)	Cumulative relative importance (%)
			Students/parents	Faculty/staff	Alumni	Corporate	Local community	Continuous improvement	Quality assurance	Cost efficiency	Real-world exposure	Graduate studies	Gender equity	Enhancing diversity & equality	Professional growth (faculty/staff)	Incorporating technology into teaching	Innovation in teaching	Curriculum innovation	Industrial partnerships	International cooperation	Resource management	Gaining money	Improving efficiency	Improving assets utilization	Minimizing risks	Success and growth			
Socio-culture	Addressing sustainability in curricula	66.6		1				1	1								1	1									333.0	4.5	40.89
	Addressing ethics and professionalism in the curricula	66.6		1				1	1									1									266.4	3.6	
	Enhancing international cooperation and partnership	34.3		1				1	1		1			1												1	205.8	2.8	
	Sustainability-oriented research	36.0		1				1	1			1			1				1	1							252.0	3.4	
	Community engagement, philanthropy & volunteerism	73.2	1	1	1		1	1	1													1				1	585.6	8.0	
	Heritage conservation & respect of cultural beliefs	51.9	1	1	1			1	1													1					311.4	4.2	
	Addressing health, safety, and well-being	73.2	1		1		1	1	1								1	1	1			1					658.8	8.9	
	Enhancing diversity and equality	50.4		1				1	1					1													201.6	2.7	
	Enhancing gender equity	49.3	1					1	1				1														197.2	2.7	
Environment	Reducing energy consumption	56.6						1	1	1										1	1				1		339.6	4.6	25.27
	Reducing water consumption	77.0						1	1	1										1	1				1		462.0	6.3	
	Waste management	53.7						1	1	1								1		1	1						322.2	4.4	
	Minimizing CO2 emissions	66.3						1	1	1								1		1	1						397.8	5.4	
	Clean and renewable energy research	56.6		1	1			1	1			1								1							339.6	4.6	
Economy	Enhancing knowledge-based economy	36.0		1	1	1	1	1	1			1			1	1			1	1			1				432.0	5.9	33.84
	Generation of business	44.8		1	1		1	1	1			1							1	1		1	1				448.0	6.1	
	Enrichment of job market	44.8	1	1	1	1		1	1		1	1	1		1	1	1	1	1	1						1	716.8	9.7	
	Local university expenditures	44.8						1	1	1											1	1	1	1			313.6	4.3	
	Economically autonomous universities	44.8				1	1	1	1	1									1	1	1	1	1	1	1	1	582.4	7.9	
Sum (score)			292	561	381	126	272	1027	1027	343	79.1	218	94.1	84.7	117	80.8	185	371	280	517	343	333	170	89.6	178	197	7365.8		
Relative importance of BSC aspects in satisfying sustainability requirements (%)			4.0	7.6	5.2	1.7	3.7	13.9	13.9	4.7	1.1	3.0	1.3	1.1	1.6	1.1	2.5	5.0	3.8	7.0	4.7	4.5	2.3	1.2	2.4	2.7			
Cumulative relative importance (%)			22.15					39.01							25.70							13.14							

Figure 2. QFD–BSC design parameters versus sustainability requirements.

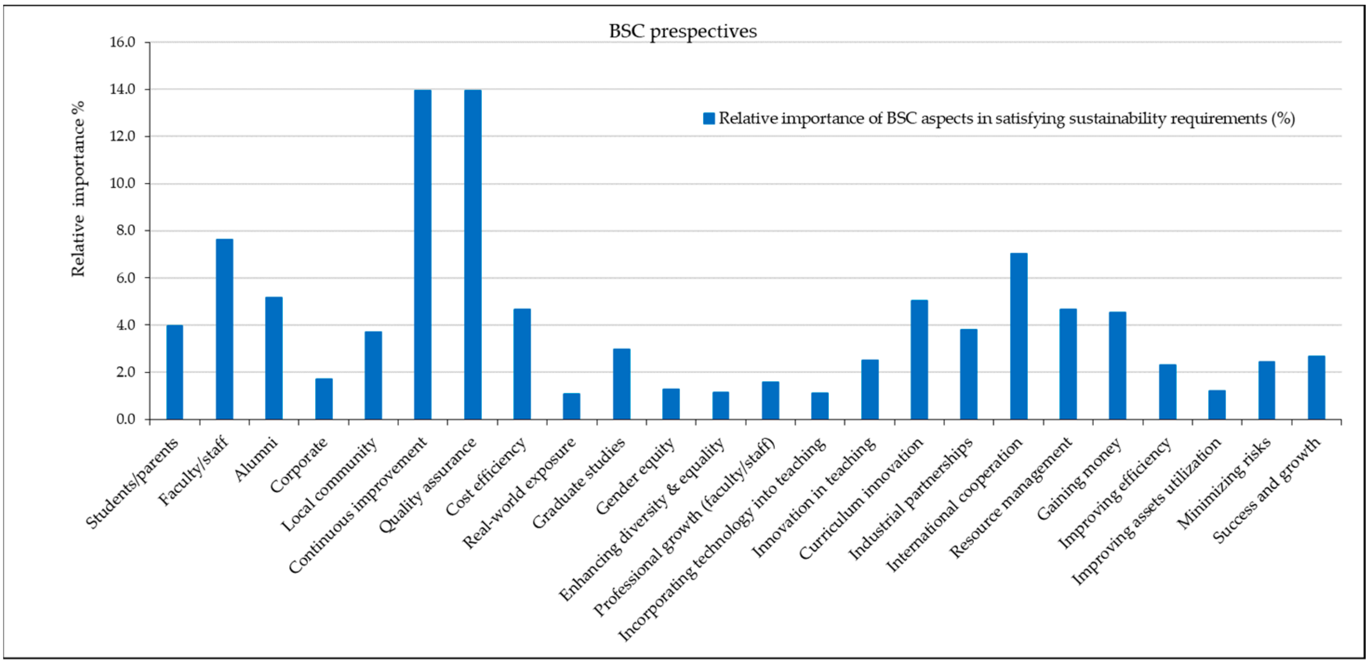

Figure 3. Design parameters of an engineering education system, BSC perspectives.

Figure 4 illustrates that the major contribution of engineering education in meeting the sustainability requirements of the society is its enrichment of the job market (9.8%) and the improvement of health, safety, and wellbeing of the society (9%). This is followed by community engagement, philanthropy, and volunteerism (8%) and developing economically autonomous universities (7.9%). On the bottom of the line, one can find enhancing diversity and equality and enhancing gender equity (2.7%). It seems that engineering education is not focused on these two aspects.

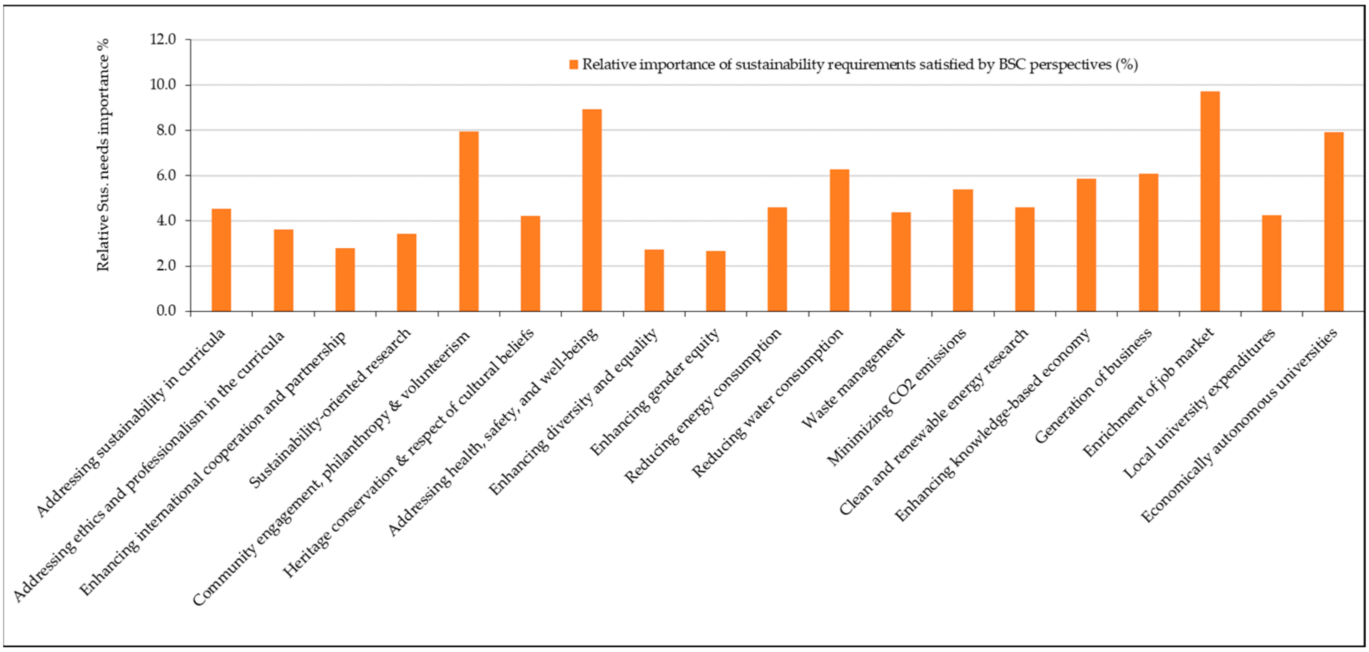

Figure 4. Relative importance of sustainability requirements met by the BSC perspectives (%).

In order to evaluate the ability of the engineering education system to meet the SDGs, Figure 5 represents a QFD in which the SDGs are considered as the customer requirements, while the engineering education system is presented by the sustainability aspects it can achieve. As previously stated, a well-designed engineering education system is capable of addressing at least 12 out of the 17 SDGs.

Order	SDGs	Importance of SDGs as per [32]	SDG relative importance (%)	Socio-culture requirements									Ecological footprint					Economic requirements					Degree of satisfying SDG by the system
				Addressing sustainability in curricula	Addressing ethics and professionalism in the curricula	Enhancing international cooperation and partnership	Sustainability-oriented research	Community engagement, philanthropy & volunteerism	Heritage conservation & respect of cultural beliefs	Addressing health, safety, and well-being	Enhancing diversity and equality	Enhancing gender equity	Reducing energy consumption	Reducing water consumption	Waste management	Minimizing CO2 emissions	Clean and renewable energy	Enhancing knowledge-based economy	Generation of business	Enrichment of job market	Local university expenditures	Economically autonomous universities	
	Relative sus. requirements importance (%)			4.521	3.617	2.794	3.421	7.95	4.228	8.944	2.737	2.677	4.61	6.272	4.374	5.401	4.61	5.865	6.082	9.731	4.258	7.907	
1	SDG6: clean water	77.0	11.7											1									6.3
2	SDG3: well-being	73.2	11.1					1		1													16.9
3	SDG4: quality education	66.6	10.1	1	1																		8.1
4	SDG13: climate change	66.3	10.0													1							5.4
5	SDG7: clean energy	56.6	8.6										1				1						9.2
6	SDG12: responsible production and consumption	53.7	8.1												1								4.4
7	SDG11: sustainable cities	51.9	7.9						1														4.2
8	SDG10: reduced inequality	50.4	7.6								1												2.7
9	SDG5: gender equity	49.3	7.5									1											2.7
10	SDG8: economic growth	44.8	6.8																1	1	1	1	28.0
11	SDG9: industry, innovation, and infrastructure	36.0	5.5				1											1					9.3
12	SDG17: partnership	34.3	5.2			1																	2.8

Figure 5. Sustainability requirement from an engineering education system versus 12 SDGs.

Figure 6 represents a comparison between the degrees to which the educational system is capable of attaining the SDGs as compared to the global importance of these goals. It is clear that the engineering education system attains SDG8: economic growth to a very large extent, followed by SDG3: good health and wellbeing, SDG9: industry innovation and infrastructure, and SDG7: affordable and clean energy.

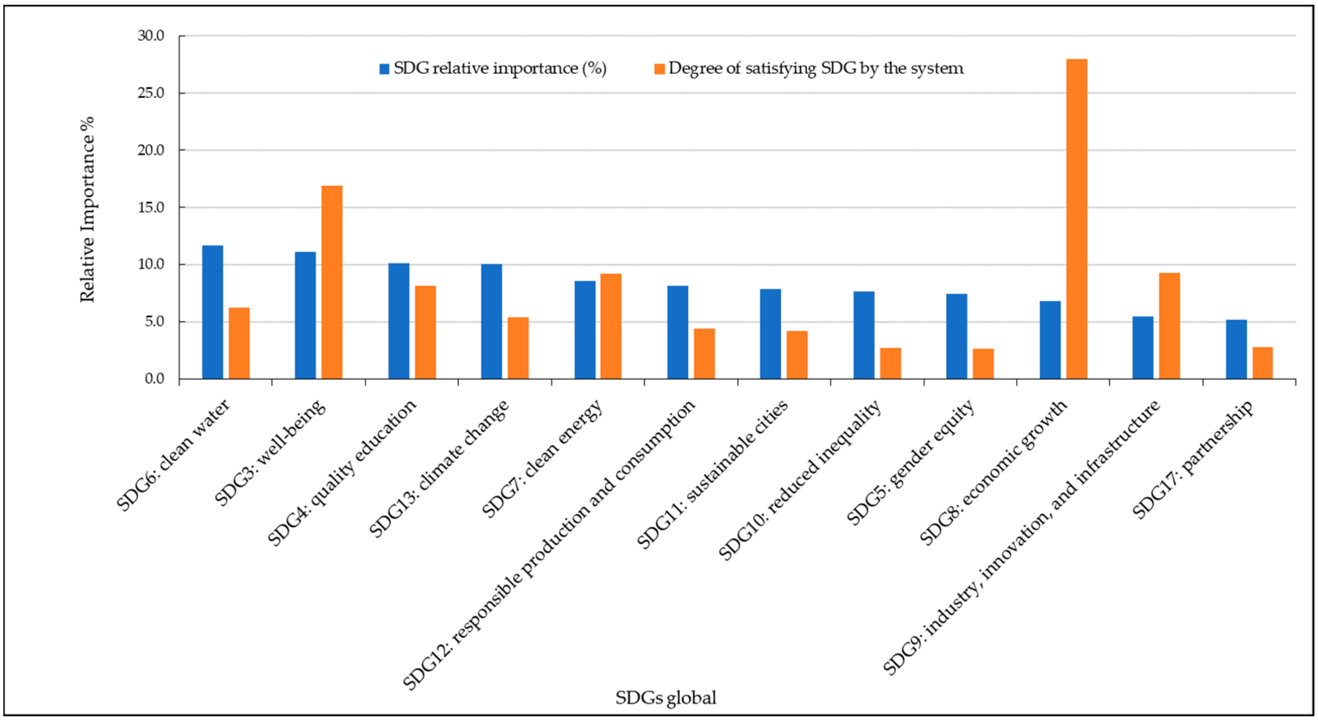

Figure 6. Attainment of 12 SDGs as compared to their global importance.

Although the engineering education system seems to have no direct connection, in the present formulation, with the most important SDG of zero hunger (SDG1) and that of no poverty (SDG3), it is clear that economic growth, which is largely satisfied, should help in achieving both of them [31].

Life on land (SDG7) and life underwater (SDG8), on the other hand, can be achieved by some engineering specialization, including mechanical and civil engineering for SDG7 and maritime engineering for SDG8.

The sustainable development goal of peace and justice (SDG 10) is far from being easily linked to engineering education in the present formulation. Nevertheless, addressing ethics and professionalism in engineering curricula, as a requirement of all engineering accreditation systems [43], is a way to have responsible graduates working for peace and justice.

3.2. Second Set of Results: Possibility of Addressing All of the 17 SDGs

In this part, an attempt was made to include the above-mentioned five SDGs as customer sustainability requirements. In order to start this activity, Table 6 is first modified to include these new goals and their sustainability indicators as shown in Table 10.

Table 10. Sustainability indicators for SDGs 1, 2, 14, 15, and 16.

Elements of TBL	Measures of Excellence	UN's SDGs	Sustainability Indicators
Socio-cultural impacts	Poverty reduction research	SDG1: no poverty	35. Percentage of MS and PhD theses that address poverty reduction objectives.
			36. Percentage of poverty reduction research projects from the total number of projects funded by the institution in one year.
			37. Percentage of funds provided for poverty reduction research from the total research fund provided by the institution in one year.
			38. Proportion of faculty working on poverty reduction research.
			39. Proportion of sustainability-related ISI publications and patents on poverty reduction issues of the total ISI publications and patents in one year.
	Hunger reduction research	SDG2: zero hunger	40. Percentage of MS and PhD theses that address hunger reduction objectives.
			41. Percentage of hunger reduction research projects from the total number of projects funded by the institution in one year.
			42. Percentage of funds provided for hunger reduction research from the total research fund provided by the institution in one year.
			43. Proportion of faculty working on hunger reduction research.
			44. Proportion of sustainability-related ISI publications and patents on hunger reduction issues of the total ISI publications and patents in one year.
	Addressing peace and justice in curricula	SDG16: peace and justice	45. Percentage of courses that address peace and justice in the curriculum.
	Addressing life on land in curricula	SDG15: life on land	46. Percentage of courses that address life on land in the curriculum.
	Addressing life below water in curricula	SDG14: life below water	47. Percentage of courses that address the life under water in the curriculum.

Figure 7 represents the modified QFD to possibly address all of the 17 SDGs. Following the same logical presentation, Figure 7 will replace Figure 2, Figure 8 will replace Figure 3, and Figure 9 will replace Figure 4. In this case, engineering education addresses the sustainability TBL requirements in a more unequal way with more concentration on the socio-cultural requirements (54% instead of 40% in the previous approach) and less concentration on environmental (20% instead of 25%) and economic (26% instead of 34%) ones.

	Sustainability requirements (customer needs) \ BSC perspectives (Design Parameters)	Weight	Customer perspective					Internal process perspective							Learning and growth perspective							Financial perspective					Sum (score)	Relative importance of sustainability requirements satisfied by BSC perspectives (%)	Cumulative relative importance (%)
			Students/parents	Faculty/staff	Alumni	Corporate	Local community	Continuous improvement	Quality assurance	Cost efficiency	Real-world exposure	Graduate studies	Gender equity	Enhancing diversity & equality	Professional growth (faculty/staff)	Incorporating technology into teaching	Innovation in teaching	Curriculum innovation	Industrial partnerships	International cooperation	Resource management	Gaining money	Improving efficiency	Improving assets utilization	Minimizing risks	Success and growth			
Socio-culture	Addressing sustainability in curricula	66.6		1				1	1								1	1									333.0	3.5	54.30
	Addressing ethics and professionalism in the curricula	66.6		1				1	1									1									266.4	2.8	
	Enhancing international cooperation and partnership	34.3		1				1	1		1			1												1	205.8	2.2	
	Sustainability-oriented research	36.0		1				1	1			1			1				1	1							252.0	2.6	
	Community engagement, philanthropy & volunteerism	73.2	1	1	1		1	1	1													1				1	585.6	6.1	
	Heritage conservation & respect of cultural beliefs	51.9	1	1	1			1	1													1					311.4	3.3	
	Addressing health, safety, and well-being	73.2	1		1		1	1	1								1	1	1			1					658.8	6.9	
	Enhancing diversity and equality	50.4		1				1	1					1													201.6	2.1	
	Enhancing gender equity	49.3	1					1	1				1														197.2	2.1	
	Poverty reduction research	76.1		1				1	1			1			1				1	1							532.7	5.6	
	Hunger reduction research	78.7		1				1	1			1			1				1	1							550.9	5.8	
	Addressing peace and justice	54.6		1				1	1		1			1												1	327.6	3.4	
	Addressing life on land in curricula	65.5		1				1	1		1			1												1	393.0	4.1	
	Addressing life below water in curricula	59.6		1				1	1		1			1												1	357.6	3.8	
Environment	Reducing energy consumption	56.6						1	1	1										1	1				1		339.6	3.6	19.53
	Reducing water consumption	77.0						1	1	1										1	1				1		462.0	4.8	
	Waste management	53.7						1	1	1								1		1	1						322.2	3.4	
	Minimizing CO2 emissions	66.3						1	1	1								1		1	1						397.8	4.2	
	Clean and renewable energy research	56.6		1	1			1	1			1								1							339.6	3.6	
Economy	Enhancing knowledge-based economy	36.0		1	1	1	1	1	1			1			1	1			1	1			1				432.0	4.5	26.16
	Generation of business	44.8		1	1		1	1	1			1							1	1		1	1				448.0	4.7	
	Enrichment of job market	44.8	1	1	1	1		1	1		1	1	1		1	1	1	1	1	1						1	716.8	7.5	
	Local university expenditures	44.8						1	1	1											1	1	1	1			313.6	3.3	
	Economically autonomous universities	44.8				1	1	1	1	1									1	1	1	1	1	1	1	1	582.4	6.1	
Sum (score)			292	896	381	126	272	1361	1361	343	259	373	94.1	264	272	80.8	185	371	434	671	343	333	170	89.6	178	377	9527.6		
Relative importance of BSC aspects in satisfying sustainability requirements (%)			3.1	9.4	4.0	1.3	2.9	14.3	14.3	3.6	2.7	3.9	1.0	2.8	2.9	0.8	1.9	3.9	4.6	7.0	3.6	3.5	1.8	0.9	1.9	4.0			
Cumulative relative importance (%)			20.64					42.57							24.74							12.05							

Figure 7. QFD: addressing all of the 17 SDGs.

Figure 8 shows that the most important aspects of the engineering education system in addressing the sustainability requirements of the society remain its commitment to continuous improvement and quality assurance (14.4% instead of 14%), followed by faculty and staff satisfaction (9.7% instead of 7.7%), international cooperation (7% as it was), industrial partnership (4.6% instead of 3.8%), and engagement with alumni (4% instead of 5.2%). On the contrary, the lowest important aspects are incorporating technology in teaching (0.8% instead of 1.1%), followed by improving assets utilization (0.9% instead of 1.2%). Generally speaking, the changes are small except for faculty and staff who take more responsibility in addressing these additional requirements.

Figure 9 illustrates that the major contribution of engineering education in satisfying the sustainability requirements of the society remains its enrichment of the job market (7.5%) and improvement of health, safety, and wellbeing of the society (6.9%). This is followed by community engagement, philanthropy, and volunteerism (6.1%), and developing economically autonomous universities (6.1%). While these are the same major contributions in the previous case but with slightly lower percentages, enhancing diversity and equality and enhancing gender equity remain at the bottom of the line with 2.1%. The newly introduced sustainability requirements of hunger reduction and poverty reduction come just after these, with 5.6% and 5.4%, respectively.

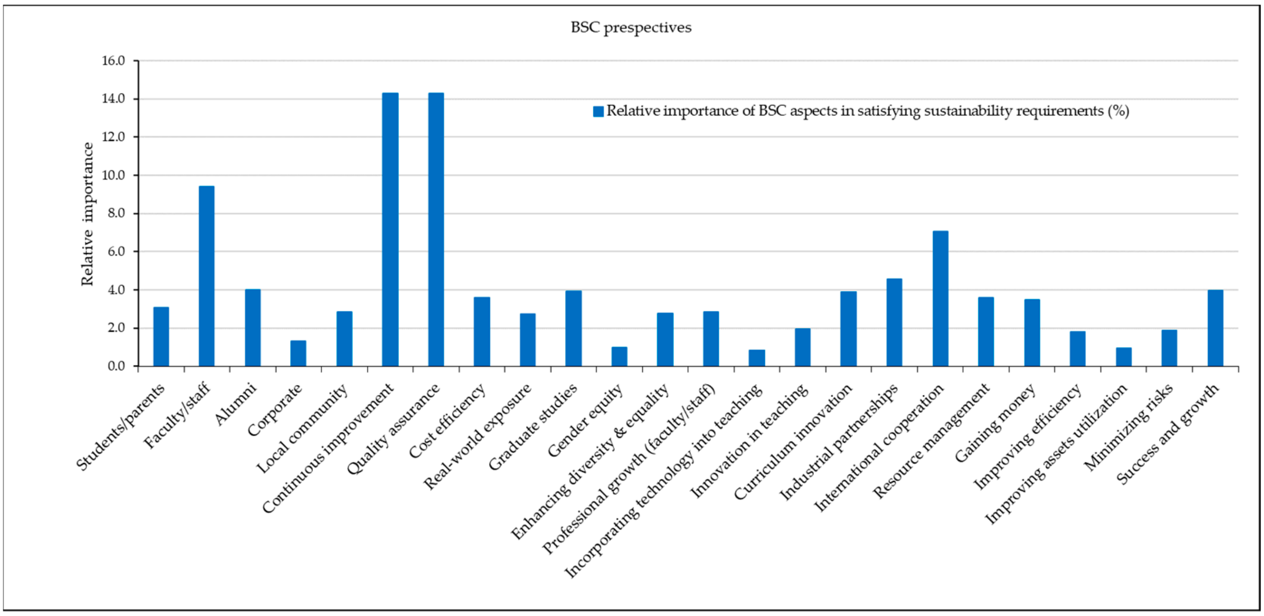

Figure 8. Design parameters of the modified engineering education system, BSC perspectives.

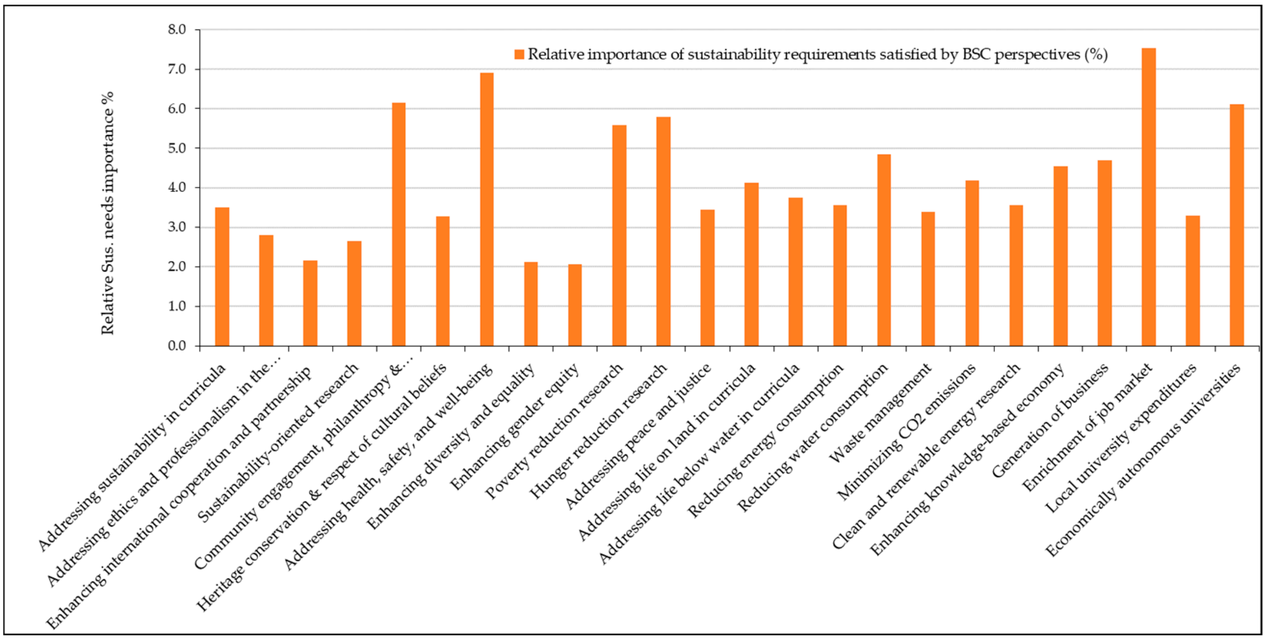

Figure 9. Relative importance of modified sustainability requirements satisfied by BSC perspectives (%).

In order to evaluate the ability of the engineering education system to possibly satisfy all the 17 SDGs, Figure 10 represents a QFD in which the 17 SDGs are considered as the customer requirements, while the engineering education system is presented by the sustainability aspects it can achieve. It is clear that a well-designed engineering education system is capable of addressing the majority of the seventeen SDGs.

Figure 11 represents a comparison between the degrees to which the educational system is capable of attaining the SDGs as compared to the global importance of these goals. It is clear that, as in the previous case, the engineering education system attains SDG8: economic growth to a very large extent (20.6%), followed by SDG4: quality education (13.5%), SDG3: good health and wellbeing (12.5%), SDG9: industry, innovation, and infrastructure and SDG7: affordable clean energy (6.8%). The newly introduced SDGs appears as follows: SDG16: peace and justice (5.9%), SDG2: zero hunger (5.5%), SDG1: no poverty (5.3%), SDG15: life on land (3.9%), and SDG14: life below water (3.6%).

Order	SDGs	Importance of SDGs as per [32]	SDG relative importance (%)	Socio-cultural requirements														Ecological footprint					Economic requirements					Degree of satisfying SDG by the system
				Addressing sustainability in curricula	Addressing ethics and professionalism in the curricula	Enhancing international cooperation and partnership	Sustainability-oriented research	Community engagement, philanthropy & volunteerism	Heritage conservation & respect of cultural beliefs	Addressing health, safety, and well-being	Enhancing diversity and equality	Enhancing gender equity	Poverty reduction research	Hunger reduction research	Addressing peace and justice	Addressing life on land in curricula	Addressing life underwater in curricula	Reducing energy consumption	Reducing water consumption	Waste management	Minimizing CO2 emissions	Clean and renewable energy	Enhancing knowledge-based economy	Generation of business	Enrichment of job market	Local university expenditures	Economically autonomous universities	
	Relative sus. requirements importance (%)			3.5	2.8	2.16	2.64	6.15	3.27	6.91	2.12	2.07	5.59	5.78	3.44	4.12	3.75	3.56	4.85	3.38	4.18	3.56	4.53	4.7	7.52	3.29	6.11	
1	SDG2: zero hunger	78.7	8.6											1														5.8
2	SDG6: clean water	77.0	8.4																1									4.8
3	SDG1: no poverty	76.1	8.3										1															5.6
4	SDG3: well-being	73.2	8.0					1		1																		13.1
5	SDG4: quality education	66.6	7.3	1	1											1	1											14.2
6	SDG13: climate change	66.3	7.2																		1							4.2
7	SDG15: life on land	65.5	7.2													1												4.1
8	SDG14: life underwater	59.6	6.5														1											3.8
9	SDG7: clean energy	56.6	6.2															1				1						7.1
10	SDG16: peace & justice	54.6	6.0		1										1													6.2
11	SDG12: responsible production and consumption	53.7	5.9																	1								3.4
12	SDG11: sustainable cities	51.9	5.7						1																			3.3
13	SDG10: reduced inequality	50.4	5.5								1																	2.1
14	SDG5: gender equity	49.3	5.4									1																2.1
15	SDG8: economic growth	44.8	4.9																					1	1	1	1	21.6
16	SDG9: industry, innovation, and infrastructure	36.0	3.9				1																1					7.2
17	SDG17: partnership	34.3	3.7			1																						2.2

Figure 10. Sustainability requirement from an engineering education system versus all 17 SDGs.

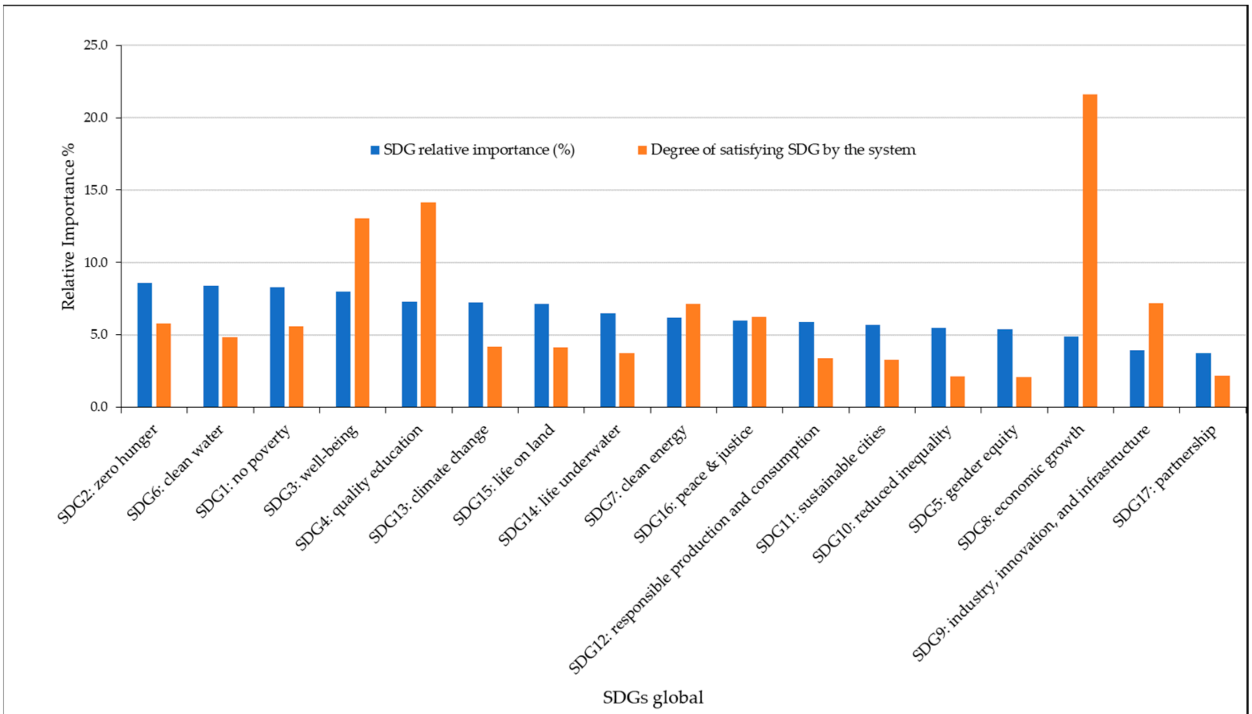

Figure 11. Attainment of all of the 17 SDGs as compared to their global importance.

3.3. Discussion

This work aims at devising a methodology to design/redesign an engineering education system to satisfy the sustainability requirements of society. In previous years, several authors concentrated on developing assessment tools and indicators of sustainability in higher education. Nevertheless, the authors of the present study could not find attempts to integrate sustainability indicators and the UN's SDGs in the design and strategic planning of the higher education institutes.

In the present work, the problem is formulated as an engineering design problem since engineering, as a discipline, has created very systematic processes for doing design work, whether the design of products, processes, systems, or services. The authors used three well-established approaches in this formulation:

1. The sustainability TBL framework is used to identify the society requirements (formulated in the engineering design approach as customer requirements) from an engineering education system to achieve the sustainable development of the society.
2. The strategic planning BSC approach is used to identify indicators to measure and assess different aspects of a successful engineering education system including four measurement perspectives, namely, finance, customer, internal business process, and learning and growth.
3. The QFD which is a Total Quality Management tool for defining the customer's demands in the customer's own voice, prioritizing these demands, translating them into engineering requirements, and establishing targets for meeting these requirements.

Identification of customer requirements using TBL was based on a previous work of the authors and a set of face-to-face interviews with twenty faculty members. The purpose was to identify the most relevant society requirements from an engineering education system. These interviews resulted in 28 customer requirements. Due to the limited size of the sample under consideration and the fact that all interviewees are faculty members, an alternative approach was used to prioritize those customer requirements with high averages and low standard deviation values. First of all the 28 customer requirements were mapped into the UN sustainable development goals. It became clear from this work that a well-designed engineering education system may be capable of addressing at least 12 out of the 17 SDGs.

In order to prioritize these requirements and as a remedy to the limitations of the results of the interviews, the prioritized scores of the SDGs yielded in a study carried out by Yang et al. [40] were used. In their study, 366 valid questionnaires were gathered from a total of 66 countries belonging to Asia, Europe, North America, Oceania, Latin America, the Caribbean, and Africa that participated in a survey to value the SDGs.

The results of applying the QFD approach indicated that the internal process perspective is the most important in addressing the sustainability requirements of the society with approximately 40% as compared with 26% for learning and growth, 22% for the customer perspective, and less than 13% for the financial perspective. This is an expected result for education sectors and similar not-for-profit organizations.

On the other hand, engineering education addresses the sustainability TBL requirements unequally with more concentration on the socio-cultural requirements (above 40%) and less concentration on environmental (25%) and economic (34%) ones. This is not surprising since education is a socio-cultural activity on its own. Although educational activities are expected to degrade the environment by its footprint, environmentally-friendly initiatives can compensate for this effect.

It was also noticed that the major contribution of engineering education in meeting the sustainability requirements of the society is its enrichment of the job market and the improvement of health, safety, and wellbeing of the society. This is followed by community engagement, philanthropy, and volunteerism and developing economically autonomous universities. Although it is expected that enrichment of the job market is one of the main targets of a higher education system, the three other contributions were particularly important during the COVID 19 pandemic. The commitment of the universities, and engineering education, to the improvement of health, safety, and well-being of the society was very important and reflected on students, faculty, and the whole society through community engagement and voluntary activities. University hospitals and engineering research and design activities contributed to dealing successfully with the pandemic. Additionally, with a lot of resources used for hygienic on-campus measures during the first couple of months before closing the university premises in several countries, normal equipment and software acquisitions were halted except for the universities that had sufficient self-generated resources.

Although the engineering education system seems to have no direct connection, in the present formulation, with the most important SDG of zero hunger (SDG1) and that of no poverty (SDG3), it is clear that economic growth, which is largely satisfied, should help in achieving both of them. Additionally, life on land (SDG7) and life underwater (SDG8) can be achieved by some engineering specialization, including mechanical and civil engineering for SDG7 and maritime engineering for SDG8. Finally, the sustainable development goal of peace and justice (SDG 10) is far from being easily linked to engineering education in the present formulation. Nevertheless, addressing ethics and professionalism in engineering curricula, as a requirement of all engineering accreditation systems, is a way to have responsible graduates working for peace and justice.

For the sake of completeness, an attempt was made to include the above-mentioned five SDGs as customer sustainability requirements. For this purpose 13 additional requirements were identified and the QFD was modified to include these additional requirements. It could be concluded that an engineering education could contribute to possibly meeting all of the 17 SDGs of the UN for 2030 to some extent. This will put additional pressure on the education system and may affect, slightly, the ability of the system to satisfy the most relevant 12 SDGs.

The authors can conclude that the methodology presented in this work allows attaining better design and strategic planning of engineering education systems while ensuring better alignment with the sustainability requirements of the society. It also enhances the resilience of the educational process and its preparedness for emergency situations.

For future work, more attention when applying the method should be given to the identification of the societal requirements from the engineering education system. This activity should be carried out by knowledgeable social groups from different societal sectors and should not be limited to faculty members and education specialists.

4. Conclusions

A method to integrate the Balanced Scorecard (BSC) approach with the Quality Function Deployment (QFD) method is used to investigate the ability of a well-designed engineering education system to address the sustainability requirements of the society. A large number of quality indicators of the system, covering all aspects of the BLC, is presented. The sustainability requirements of the society and their indicators are considered as the customer needs, or the WHATs, in the QFD method, while the quality indicators of the BSC represent the design aspects, or the HOWs, of the system. A simplified binary system of zeros and ones describes the degree to which the BSC indicators address the customer requirements.

The use of the House of Quality allowed reviewing and improving the developed performance indicators by measuring the extent of their relevance to sustainability requirements of the society. The process required several iterations to ensure that the elements in the HOWs are sufficient to address all the WHATs. In several cases, it was necessary to add additional HOWs with their performance indicators, modify some performance indicators, and/or reformulate some WHATs and their indicators to be more specific to the designed system under consideration.

Engineering education could contribute to meeting all of the 17 SDGs of the UN for 2030 to some extent. Although the engineering education system seems to have no direct connection, in the present formulation, with the most important goal of zero hunger (SDG1) and that of no poverty (SDG3), it is clear that its contribution to the economic growth should help in achieving both of them. The same applies to the goals related to life on land (SDG7) and life underwater (SDG8) which are related only to a certain number of engineering specializations. Finally, the sustainable development goal of peace and justice (SDG 10) is far from being easily linked to engineering education in the present formulation.

On the other hand, engineering education could be a key player to achieve the sustainable development goal SDG8: economic growth in addition to SDG4: quality education and SDG3: good health and wellbeing and SDG9: industry innovation and infrastructure.

Applying the methodology presented in this work allows attaining better design and strategic planning of engineering education systems to ensure better alignment with the sustainability requirements of the society. It also enhances the resilience of the educational process and its preparedness for emergency situations. Nevertheless, more attention when applying the method should be given to the identification of the societal requirements from the engineering education system which should be carried out by knowledgeable social groups from different societal sectors and should not be limited to faculty members and education specialists.

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