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Sustainability Engineering Education – An Outlook On Uk Higher Education Providers

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SUSTAINABILITY ENGINEERING EDUCATION – AN OUTLOOK ON UK HIGHER EDUCATION PROVIDERS

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ABSTRACT

The aim of this paper is to assess the extent to which United Kingdom (UK) universities are incorporating sustainability into their engineering curricula. To achieve this, data from the Universities and Colleges Admissions Service (UCAS) and university websites were analysed using a text mining approach. The findings reveal that UK higher education providers are gradually increasing their offerings of Sustainable Engineering (SE) courses at both undergraduate and postgraduate levels. The most prominent sustainability themes integrated into engineering curricula are energy, design, and construction. Furthermore, the analysis of courses and their modules shows that 50% of UK postgraduate sustainable engineering courses contain between 25% and 50% sustainable engineering content. In contrast, almost one-third of traditional engineering courses that incorporate sustainability contain between 10% and 25% of sustainable engineering subjects. The study also examined the SE courses and their module descriptions to identify gaps and how UK higher education providers are contributing towards the United Nations Sustainable Development Goals (SDGs). The most dominant SDGs addressed in the UK SE courses analysed are SDG 7 Affordable and Clean Energy, SDG 9 Industry, Innovation and Infrastructure, SDG 11 Sustainable Cities and Communities, and SGD 13 Climate Action. This paper provides valuable insights into the integration of sustainability into engineering education and its alignment with the SDGs.

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1 INTRODUCTION

The global expansion of sustainable development principles over the recent years shows how important integration of sustainability in the engineering curriculum has become for Higher Education (HE) providers. Universities are taking an important role in vocational and skills training for sustainable development (SD) and it is being offered mostly at postgraduate than undergraduate level. Despite the inclusion of sustainability in engineering education in recent years, there are still challenges in the curriculum design and learning environment, and how the adoption of these curricula aligns with 17 United Nations Sustainable Development Goals (SDGs) and their priorities (United Nations, 2015, 2016).

Integrating sustainability competencies in engineering education is challenging and often lacks strategic and systematic planning (Beagon et al., 2023; Jordi Segalàs Coral, 2009, pp. 14–21; Leifler & Dahlin, 2020; Perpignan et al., 2020). Miñano Rubio et al. 2019) in their studies suggest that an appropriate model for systematically developing sustainability competencies within the engineering curriculum should be based on three pillars, such as the inclusion of sustainability principles in compulsory courses and in academic project activities, and lastly embedding sustainability content into appropriate courses along the curriculum.

Another challenge is the sustainability content in the engineering programs and how the implementation of sustainability content into traditional engineering courses benefits students and SDGs. In Australia and elsewhere, studies were conducted to understand the current status of universities regarding the implementation of sustainability content in engineering curricula (Arefin et al., 2021; Balakrishnan et al., 2021; Filho et al., 2021; Monna et al., 2022; Murphy et al., 2009; Sánchez-Carracedo et al., 2022; Thürer et al., 2018). Environment and Energy was the most common theme stated in these studies. Studies elsewhere also found that ethical and social sustainability issues do not appear explicitly, there is still a need for understanding the expectations and skills sought by future employers and how universities can integrate them the engineering curriculum (Akeel et al., 2019; Edvardsson Björnberg et al., 2015; Kamp, 2006).

Moreover, some studies have have looked into the insight of modes of course delivery adopted by universities related to the implementation of SD in their engineering curricula, among others stand-alone courses (Hegarty et al., 2011), integrated sustainability content into conventional engineering curricula (Zanitt et al., 2022), continuous professional development courses (Pérez-Foguet et al., 2018), online or distance learning (Simson & Davis, 2022). Despite the challenges discussed in these studies, there is a focus on the learning objectives to be met regardless of the delivery mode. A guide for universities around the world has been published to accelerate action on SDGs (SDSN Australia/Pacific, 2017) and how universities can incorporate sustainability into engineering programs among others (RAENG, 2005; UNESCO, 2021).

Given (i) the urgent need for aligning, not only the objectives of HE, but also the means that develop competencies, with the sustainable trajectories that modern societies are willing to undertake, (ii) the role of the sector in shaping the mindsets and enhancing the skillsets of the leaders of the future, and (iii) the circular role of sustainability in HE, this paper aims to provide an outlook of the undergraduate and postgraduate engineering courses offered by the United Kingdom (UK) higher education providers that address sustainability engineering in their curriculum for improving observability of current situation and triggering actions towards the necessary direction. The paper is organised as follows; Section 2 presents the methodology that has been used in this study and provides the necessary details about the data gathering, processing and analysis. Section 3 presents the key outcomes of the analysis and discusses the results, while Section 4 concludes the paper and indicates possible extensions as future work.

2 METHODOLOGY

According to the Universities and Colleges Admissions Service (UCAS), there were over 50,000 HE courses available in the UK in 2021, including undergraduate and postgraduate programs across different fields of study, while the engineering and technology-related subjects were among the top five most popular subject areas for higher education in the UK, with over 302,000 students enrolled based on data from the Higher Education Statistics Agency (HESA). This number includes both undergraduate and postgraduate programs from 165 HE providers in various fields of engineering, such as mechanical engineering, electrical engineering, civil engineering, and chemical engineering, among others.

To grasp an overview and analyse the trends in the UK higher education sector around the integration of sustainability in the engineering curricula, a structured navigation method to process the available information with emphasis on the present (2022-2023) and next academic years (2023-2024), and a text-mining-based approach were deemed suitable. Therefore, an adaptation of the generic "Cross-Industry Standard Process for Data Mining" (CRISP-DM) methodological framework (Miner et al., 2012) was introduced, with the phases being presented in Figure 1.

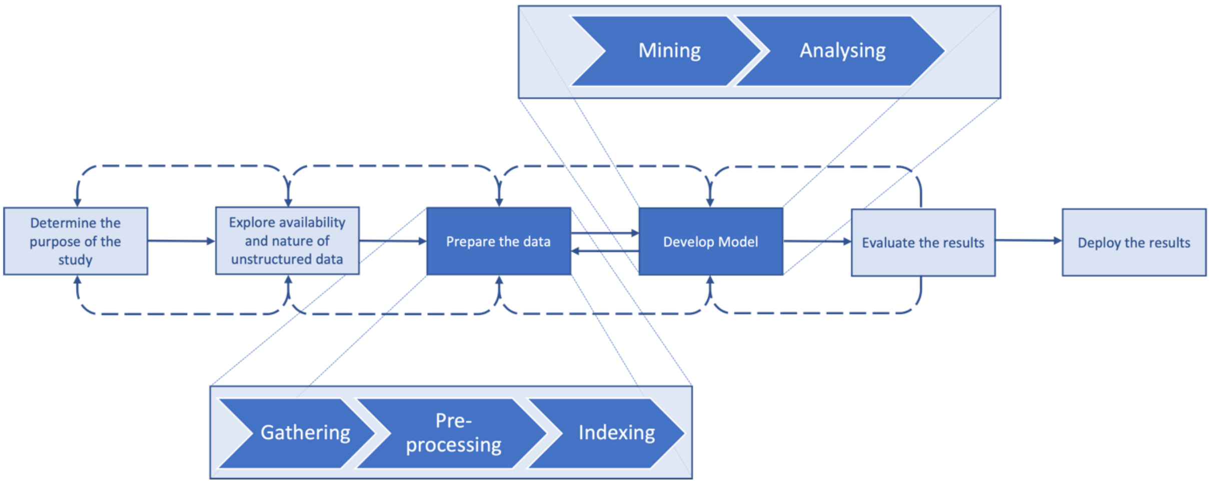

Figure 1: The introduced methodological framework that follows the phases of CRISP-DM. Adopted from (G. D. Miner et al., 2012).

Following the six phases of CRISP-DM, first, the study's purpose and objectives were defined and then the data requirements and sources were identified, with the initial data collection and exploration being performed and potential issues or opportunities were identified, including more specifically, the higher education providers and details of the relevant undergraduate (UG) and (PG) postgraduate course they offer. Next, in the data preparation phase, the data, including the underlying themes covered in the UG and PG courses as well as the sustainability-related content in the PG "sustainability-" and "conventional-" engineering programmes, was cleaned, transformed, and pre-processed to make it suitable for the model phase. The activities (Turegun, 2019)can be considered as follows:

- Gathering - Data collection from various sources e.g. document files, websites, emails or comments, with the process being either automated or directed by the user.
- Pre-processing - Identification and extraction of descriptive characteristics from content, by removing unwanted information (text clean up), breaking the text into meaningful units (tokenization) and measuring dimensions of the text (feature extraction).
- Indexing - Particular terms are indexed with the location and the number being noted so that that the structure will allow rapid access and efficient processing of the data.

It should be mentioned that data was extracted from the Universities and Colleges Admissions Service (UCAS) and UK universities' websites. A combination of 'Engineering' and 'Sustainability' words was used in the processing activity of university-level engineering curricula, and the frequency and association between words were used to create dimensions. A total of 38 UK HE institutions were found for both undergraduate ($N_{UG} = 10$) and postgraduate ($N_{PG} = 28$) levels that had a combination of target search terms in the course title.

In the model phase, the following activities took place in a structured and supervised manner, with rules and subprocesses being dictated by the nature of the problem and the pre-processing outcomes.

- Mining - Disclosure of new information through data exploration methods for revealing specific terms, their relation between other terms and their connection to semantic representations and taxonomies.
- Analysing - The analysis utilises the raw outcomes of the mining phase, by evaluating and visualizing them according to the problem at stake the user preferences, so interpretations can be made.

More specifically, as part of the mining activity, the UG and PG courses were clustered [ref] into main engineering themes, as these were identified and formed a short dictionary consisting of the entities “Environment”, “Energy”, “Transport”, “Construction”, “Building”, “Chemical”, “Design”, “Marine”, “Propulsion”, and “Business and Management”. Moreover, an indicative example of the analysing activity constitutes the extraction of the sustainability content index, for which the level of sustainability-related content in engineering PG programs was analysed. The data that was collected from publicly available PG courses information during the data preparation phase included module descriptions of several Aeronautical ($N_{Aero} = 22$), Mechanical ($N_{Mech} = 69$), Civil & Building Management ($N_{Civil} = 99$), Materials & Manufacturing ($N_{M\&M} = 40$), Design ($N_{Dsgn} = 10$) and Sustainable Engineering ($N_{Sust} = 44$) programmes. Finally, by focusing on the Sustainable Engineering PG courses their contribution to SDG goals was analysed by identifying and categorised components of the curricula.

Finally, according to the methodological phases, the outcomes and results were evaluated (Allahyari et al., 2017) (human evaluation) and triggered a feedback loop for corrective actions on the previous phases, while the deployed results of the analysis that are presented and discussed in the next Section of the paper, complete the process.

3 RESULTS AND DISCUSSION

In this section, we present the results of our research, which aim to provide an understanding of the underlying trends of UK engineering curricula towards SDGs. The data collected and analysed correspond to two subsequent academic years, i.e., the current one, 2022-2023 and the upcoming one, 2023-2024. We start by analysing the total number of UK Higher Education universities integrating Sustainable Engineering in their curriculum at both Undergraduate and Postgraduate levels, as depicted in Figure 2.

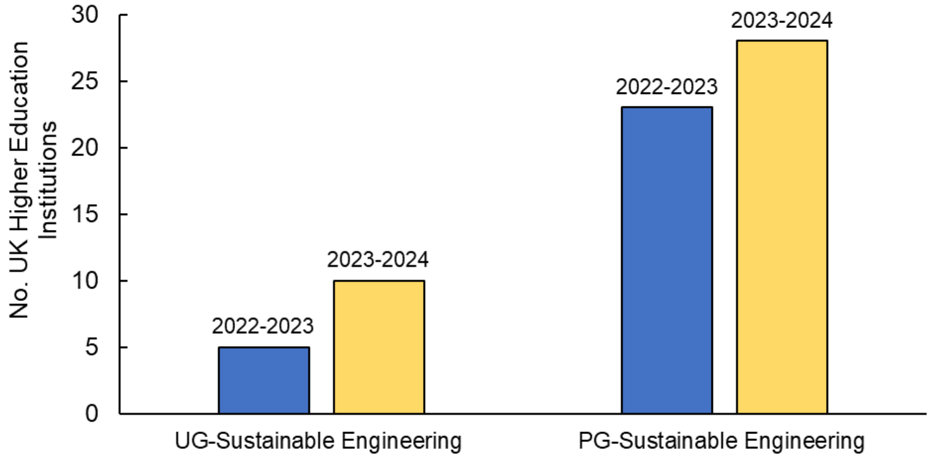

Figure 2. Integration of Sustainable Engineering into UK Higher Education Institutions' Curriculum

The number of UK Higher Education Institutions providing Sustainable Engineering undergraduate programs has doubled from 5 in the 2022-2023 academic year to 10 in 2023-2024. This indicates a 100% increase and could suggest a growing interest and focus on sustainability in engineering education. This is consistent with global trends towards more sustainable industrial practices, including engineering.

Moreover, at a postgraduate level, an increase is observed from 23 in the 2022-2023 academic year to 28 in 2023-2024, showing a growth rate of 21.7%. This suggests a continued emphasis on developing professionals in this field who can contribute to sustainable solutions at a higher level.

A more detailed review of the above findings has been conducted in terms of 'engineering theme focus'. Figure 3 illustrates the percentage distribution of different subject areas incorporating Sustainable Engineering content in their undergraduate (UG) and postgraduate (PG) programs across the two academic years 2022-2023 and 2023-2024, respectively. Comparing the data for UG programs between the two academic years, there is an increase in the percentage of Energy from 40% to 50%, while there are minor changes in the other areas of study. This suggests that there is a growing emphasis on Energy in the UG Sustainable Engineering curriculum.

In the case of PG programs, the percentage of Energy is highest at 47% for 2022-2023 and slightly drops to 45% in 2023-2024. Design, Construction & Building, and Environment have significant percentages ranging from 8% to 16% over the two academic years. Propulsion and Chemical have lower percentages ranging from 2% to 5% with minor fluctuations, while Business & Management, Transport, Industrial Systems, and Marine have lower percentages ranging from 2% to 5% and remain relatively consistent.

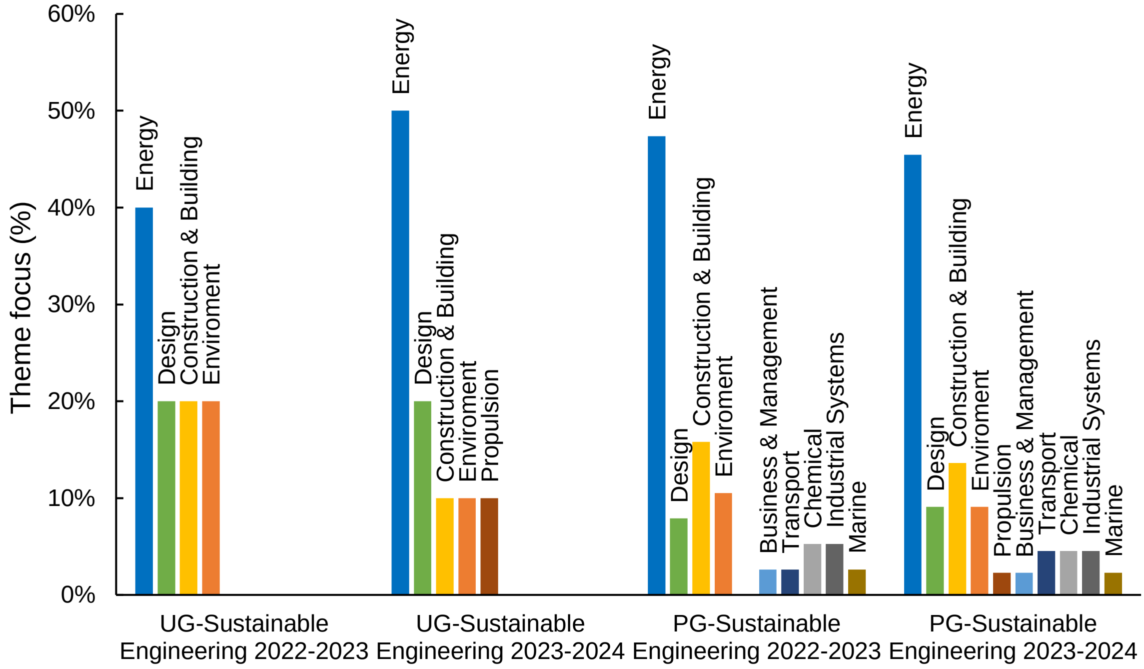

Figure 3. Themes covered in UK HE sustainable engineering courses (%)

Further analysis has been conducted on the distribution of sustainability content across various Postgraduate level Engineering programs. These programs fall into the following disciplines: Sustainable Engineering; Mechanical Engineering; Aerospace Engineering; Civil & Building Engineering; Materials/Manufacturing Engineering; and Design Engineering. And the data is categorised into five levels showing what percentage of the course content is focused on sustainability:

- 0%: No sustainability content
- 1-10%: Low sustainability content
- 10-25%: Moderate sustainability content
- 25-50%: High sustainability content
- >50%: Very high sustainability content

The data in Figure 4 showcases that PG-Sustainable Engineering notably exhibits a robust presence of sustainability content, with no modules having 0% sustainability content. Most of the modules are spread across the 1-10% (10), 10-25% (23), and 25-50% (11) categories. However, no modules primarily focus on sustainability (>50% content). PG-Mechanical Engineering and PG-Aero Engineering lean heavily towards lower sustainability content. In Mechanical Engineering, the majority of modules (45) show no sustainability content, with a small number falling within the 1-10% (23) and 10-25% (1) categories. Similarly, Aero Engineering has a significant number of units (17) with 0% sustainability content and fewer units (5) with 1-10% content.

Moreover, PG-Civil & Building Engineering and PG-Material/Manufacturing Engineering show some focus on sustainability. Despite a high number of modules (63) with 0% sustainability content in Civil & Building Engineering, it also presents a considerable number of modules (31) with 10-25% sustainability content. Material/Manufacturing Engineering has 26 modules with 0% sustainability content and 14 modules with 1-10% content. Finally, PG-Design Engineering, having the fewest modules, presents 3 with 0% sustainability content and 7 with 1-10% content.

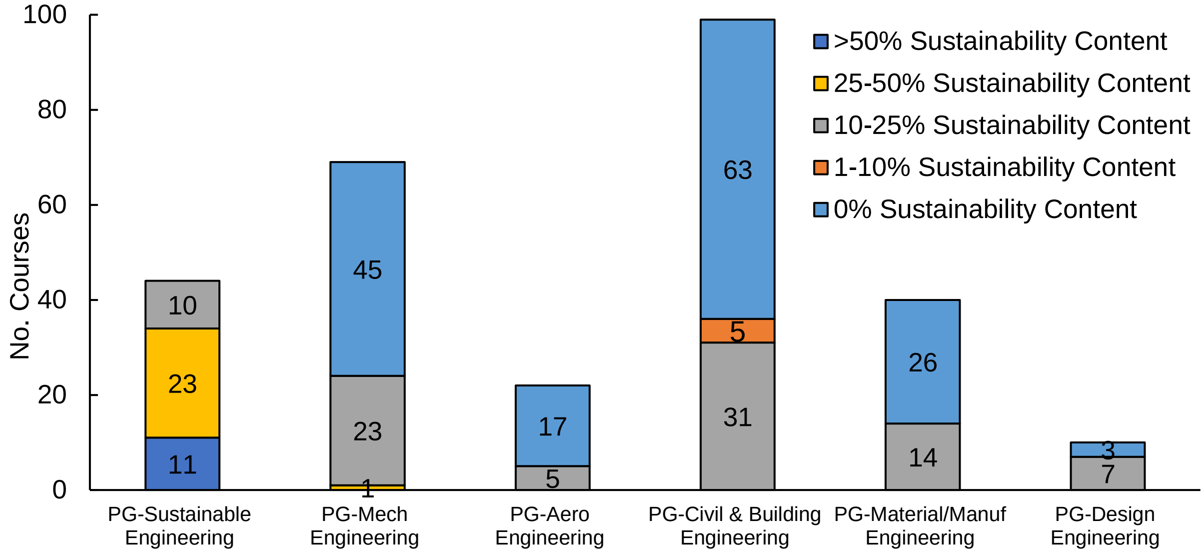

Figure 4. Sustainability Content across PG Engineering Disciplines

As a final step to our study, we attempted to identify the number of undergraduate (UG) and postgraduate (PG) courses offered across various UK institutions and map their curriculum with the 17 Sustainable Development Goals (SDGs) that the United Nations established in the '2030 Agenda for Sustainable Development'. The following data is illustrated in Figure 5:

- **SDG 3: Good Health and Wellbeing** - A total of 19 courses are offered, with 2 UG courses and 17 PG courses. This reflects the importance of health and wellbeing in the educational landscape.
- **SDG 2: Zero Hunger** - Only 2 engineering courses are available, both at a PG level. This suggests that there may be a need for more educational opportunities to address hunger and food security issues.
- **SDG 6: Clean Water and Sanitation** - There are 7 courses in total, all of them being PG courses. This may imply that water and sanitation issues are primarily addressed at a more advanced educational level.
- **SDG 7: Affordable and Clean Energy** - With 44 courses (5 UG and 39 PG), this SDG has a strong representation in the educational sector, indicating a focus on clean energy and its importance for sustainable development.
- **SDG 8: Decent Work and Economic Growth** - This goal has only 2 courses, both being PG courses. This may suggest that more attention could be given to promoting economic growth and decent work through education.
- **SDG 9: Industry, Innovation, and Infrastructure** - A total of 19 courses are offered, with 3 UG and 16 PG courses. This shows a considerable interest in fostering innovation and infrastructure development.
- **SDG 10: Reduced Inequalities** - There are only 2 PG courses addressing this SDG, indicating that more educational opportunities could be developed to tackle inequality issues.
- **SDG 11: Sustainable Cities and Communities** - This goal has 24 courses in total (3 UG and 21 PG), reflecting a strong focus on urban planning, sustainable development, and community-building.
- **SDG 12: Responsible Consumption and Production** - With 7 PG courses, this goal has a moderate representation, which could be further expanded to promote sustainable consumption and production practices.

- **SDG 13: Climate Action** - This SDG has the highest number of courses (45), with 6 UG and 39 PG courses. This demonstrates the increasing emphasis on climate change mitigation and adaptation in education.
- **SDG 14: Life Below Water** - A total of 6 courses are offered (1 UG and 5 PG). This suggests that there is some focus on marine conservation and life below water, although it could be expanded further.
- **SDG 15: Life on Land** - With only 4 PG courses, this goal has relatively limited representation, indicating a potential need for more educational opportunities focusing on terrestrial ecosystems and biodiversity conservation.

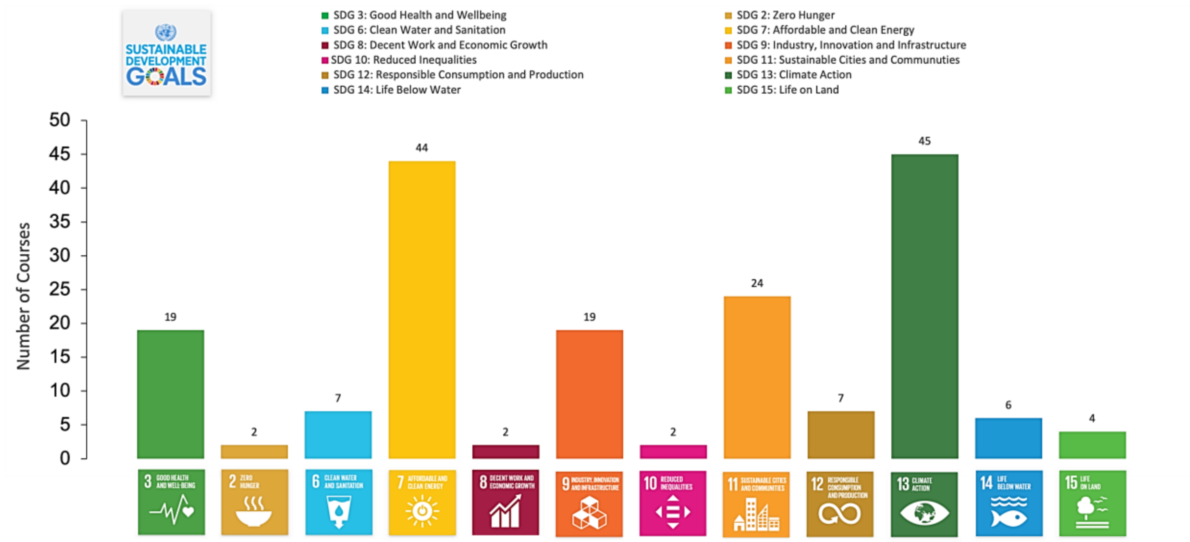

Figure 5. UK Sustainable Engineering and Sustainable Development Goals

To summarise, while certain SDGs like Climate Action, Affordable and Clean Energy, and Good Health and Wellbeing have strong educational representation in engineering courses, others like Zero Hunger, Decent Work and Economic Growth, and Reduced Inequalities could benefit from more courses to address their respective issues. It is also noteworthy that most of the courses offered are at the postgraduate level, suggesting that undergraduate programs could be further developed to encompass more SDGs.

4 CONCLUDING REMARKS

This study aimed to provide an outlook of the UK higher education providers towards SDGs initiatives in engineering curricula. A text mining approach was used to collect data from UCAS and universities website to look at trends and sustainability content in engineering courses in the UK. The data show that sustainability contents are being implemented in more than 46% of the sampled UK PG engineering courses (N=286), and the most prominent sustainability theme focus is Energy for the 2023-2024 academic year offer. More effort is needed by UK HE providers on the curricula development and provision of other themes towards SDGs including Product Desing and Sustainable Manufacturing.

In future work, we will analyse the integration of Social and Corporate Responsibility, and Ethics inclusion in UK engineering curricula.

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