education sciences

Article

What Are We Teaching Engineers about Climate Change? Presenting the MACC Evaluation of Climate Change Education

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Abstract: Engineering underpins the progress of modern societies. However, engineering activities are a key driver of climate change and engineers are responsible in many ways for disaster risk reduction. It is therefore imperative that engineering education accurately portrays the impact that the profession has on our climate and equips engineers with the knowledge to mitigate greenhouse gas emissions and to adapt infrastructure for climate resilience. Here, we explore how higher education prepares engineers to address the climate crisis via a curricula analysis of three departments (mechanical, civil, and electrical engineering). The pilot study investigated the extent of mitigation and adaptation to climate change (MACC) content across different disciplines by developing and applying an evaluation methodology. We found that module descriptions and learning objectives were largely without reference to MACC, further evidencing the dissociation of engineering education from the climate reality as cited in the literature. This novel approach goes beyond curricula analysis to integrate MACC within module outlines paving the way for future integration. This research demonstrates the urgent need for climate conscious engineering curricula.

Keywords: climate change education; engineering education; STEM education; curricula evaluation; text analysis; higher education; education for sustainable development; environmental education

Citation: Axelithioti, P.; Fisher, R.S.; Ferranti, E.J.S.; Foss, H.J.; Quinn, A.D. What Are We Teaching Engineers about Climate Change? Presenting the MACC Evaluation of Climate Change Education. *Educ. Sci.* **2023**, *13*, 153. https://doi.org/10.3390/educsci13020153

Academic Editors: Christos Dimopoulos, Maria Meletiou-Mavrotheris, George Boustras and Evangelos Katsaros

Received: 24 December 2022
Revised: 28 January 2023
Accepted: 29 January 2023
Published: 1 February 2023

1. Introduction

Engineering as a professional discipline pervades every industry, and consequently engineers play a crucial role in the functioning and development of societies. However, many students of engineering higher education courses are at risk of entering professional practice without adequate knowledge, information, or experience of climate change, its drivers, or the skills to develop solutions [1–11]. Yet, the impacts of climate change are already affecting every region globally [12] and a climate emergency has been declared in 39 nations [13].

The International Panel on Climate Change (IPCC) is the most highly regarded body in relation to climate change science and provides the most up to date understanding of climate change processes as well as understanding of climate change impacts. There are two aspects to addressing the climate change crisis: mitigation and adaptation to climate change (MACC). Climate change mitigation can be defined as "a human intervention to reduce the sources or enhance the sinks of greenhouse gases (GHGs)", whereas climate change adaptation is the "process of adjustment to actual or expected climate and its effects, in order to moderate harm or exploit beneficial opportunities" [12,14]. By breaking down the climate change challenge into historical and contemporary contexts and its two main constituent parts, mitigation and adaptation, it is possible to demonstrate the critical role that engineers play in addressing this issue.

The first challenge is mitigating climate change through the control of emissions of GHGs, which are changing the earth's atmospheric make up and consequently, driving climate change. Whilst the sources of GHG emissions are varied, over 70% are produced through the consumption of energy as shown in Figure 1, and the three key areas of energy consumption are in industry, transport, and buildings [15]. Each of the sectors is strongly supported by engineering disciplines, without which, social, technological, agricultural, and economic progress would not be possible. Engineers are the immediate inventors and implementers of new technologies, harnessing raw materials, and using energy both at the construction stage and throughout their operational life. Consequently, it is evident that engineers play a critical role in the reduction in GHG emissions and the mitigation of climate change.

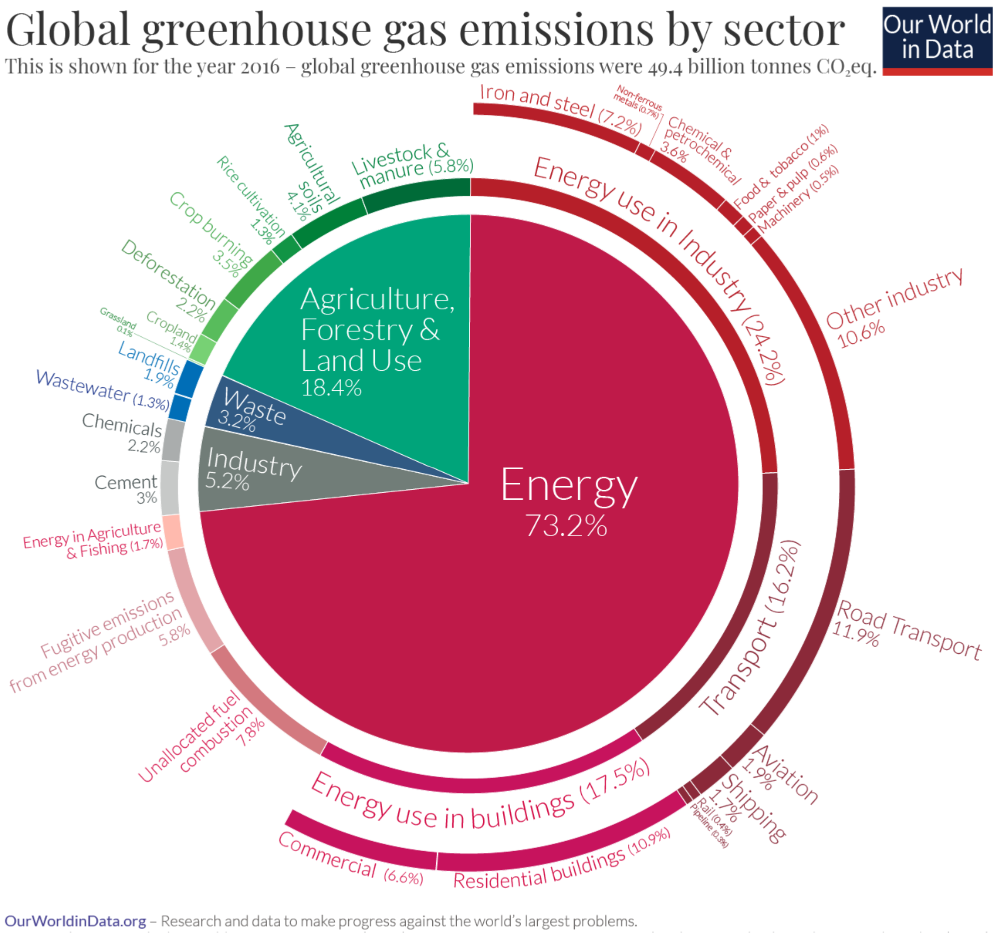

Figure 1. Global GHG emissions by sector. Source: [15].

The second challenge is adapting to climate change impacts, which primarily are more frequent and more extreme weather events and rising sea levels [12]. In the UK, climate change mitigation and adaptation are mandated under the 2008 Climate Change Act. Currently, much of the focus is on the need to mitigate climate change through actions to decarbonise sectors towards the overarching goal of reaching net-zero by 2050. In contrast, there has been a far lesser focus on adaptation. At a national level, one primary mechanism is the adaptation reporting power (ARP) which is used to gather information relating to climate risks and adaptation progress of organisations identified as reporting bodies. An overview of the organisations who participated in the third round of reporting can be seen in Figure 2 [16]. The organisations listed represent sectors which rely on a significant number of engineering professionals in their day-to-day business activities and, consequently, will rely on these engineers to support the adaptation goals of each organisation.

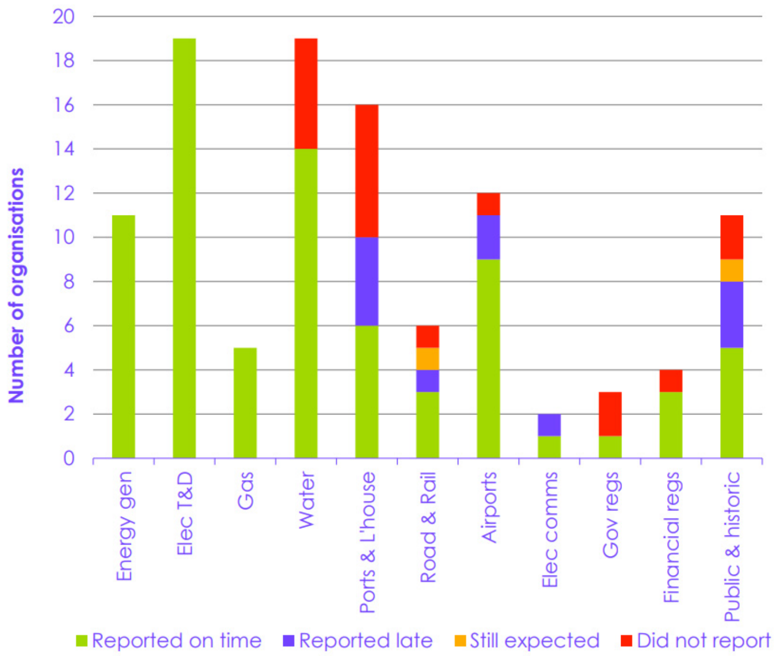

Figure 2. Profile of ARP3 Submissions. Source: [16].

Education has been identified as key mechanism for the communication of climate change, and in particular, a key tool for governments to increase awareness of this issue [17,18]. This is where engineering education plays a crucial role. As climate change manifests in more frequent and more severe weather events, the need for engineers to reinstate critical infrastructure through disaster recovery and risk management will continue to increase. Engineering education, therefore, must be a prominent educational space where knowledge, improved practices, and awareness of climate change and environmental sustainability are embedded across the curriculum.

Despite a progressive agenda for engineering in higher education outlined by the Engineering Council in the UK, the precise requirements for higher education organisations are not clear, and the extent of current delivery of climate change topics is not known. Therefore, this article presents a robust methodology to evaluate the inclusion of climate change themes within engineering higher education courses. The research objectives are as follows:

1. Establish the current state of knowledge and identify methodologies to support the analysis of the inclusion of climate change within engineering curricula.
2. Quantify current inclusion of mitigation and adaptation to climate change within higher education engineering courses.
3. Demonstrate the effective application of the MACC evaluation to a higher education engineering course in a pilot study.
4. Identify routes to improved inclusion of climate change themes and empower educators.

Section 1 has introduced the context of the research undertaken which has been informed by the literature reviewed in Section 2. This review aims to present current research regarding the role of education in communicating and addressing climate change issues. Based on approaches used in previous work, Section 3 establishes a methodology to quantify and evaluate existing higher education engineering courses for inclusion of key climate change mitigation and adaptation themes. The acronym MACC in the present study is used by approaching climate change via the routes of mitigation and adaptation, using M and A to pinpoint specific terms in engineering education and maintaining CC as the umbrella term. Hence, in the analysis of mitigation and adaptation terms, climate change investigation is also achieved. The paper proceeds to present a case study application of a novel evaluation tool called MACC evaluation, which was developed for the analysis of engineering curricula. The results of the case study are presented in Section 4. The discussion in Section 5 highlights key findings and their implications, as well as the limitations of the approach and next steps. Finally, Section 6 features concluding remarks.

2. Literature Review

There is an observed mismatch on the development between climate change research and climate change-related education. Sustainability, sustainable development, and climate change are terms that have existed in the environmental sciences and UN literature for over four decades. The Brundtland Report "Our Common Future" published almost four decades ago was the initiation point towards sustainable futures. The report provided context for what makes up sustainable development "the ability to [. . .] ensure that it [development] meets the needs of the present without compromising the ability of future generations to meet their own needs". It also provided an accurate depiction of the depletion of natural resources, the production and consumption of power, the sources and uses of water, the geographically specific challenges evident in the late 20th century, and foreshadowing many of the pressures we experience in today's reality [19]. More recently, global environmental and climate research focuses on painstakingly recording the rapid changes observed in the planet's climatic conditions, the rapid loss of biodiversity on land, in the seas and water bodies, and within animal populations, as well as plant diversity loss. Research is also focusing on solutions to diminish the losses of the natural resources and emissions in the atmosphere.

Despite this, implementation in educational contexts has been slow and inconsistent. The education literature reviewed demonstrates that research on climate change and environmental education has followed this trend in a less structured way and at a much slower pace. As the UN SDGs came to be affirmed in 2015, the efforts to augment the perception and importance of sustainable development increased rapidly, as did research on education sustainable development. We are currently entering a new era in education that centers more specifically on climate change. There is now a significant body of literature relating to environmental and sustainability education; however, this review highlights that these topics have not been sufficiently embedded in higher education engineering curricula. Furthermore, whilst the field of climate change education is still relatively less well developed, similar challenges have been identified both within school level education and higher education engineering courses. Current literature concerning sustainability education, education for sustainable development (ESD), or climate change education highlights specific challenges.

2.1. Environmental and Sustainability Education

Environmental education has traditionally omitted the impact of human activity on the environment as it focused on environmental conservation efforts [1]. Environmental education was developed in the 1970s and 1980s, while economic and educational leaders still maintained that the environmental crises could be reversed with actions towards conservation. This approach misrepresented the interconnectivity of human activity and environmental issues [1]. Since the turn of the century, education about the environment has transitioned into ESD, sustainable education, and most recently, climate change education. These areas have developed in their complexity as they try to better represent the interconnectivity of human activity, economic growth, environmental decline, and social repercussions through a holistic and pluralistic lens. Teachers, however, find these themes confusing to teach as references in syllabi and curricula have been added before teaching resources were available. A conceptual framework has been developed to address this challenge by teaching ESD on the three axes of social, environmental, and economic issues. However, this approach is challenging for students and teachers alike. Both groups can relate to social and environmental issues independently and in combination, but they struggle with the perspective of economic growth [20]. In the context-focused educational literature for sustainable development, Jóhannesson et al. (2011) showcase the meticulous work required to align curricula with sustainable development, growing routes in the inclusion of values, by developing the "GETA" (meaning "capability" in Icelandic) curriculum analysis key [3].

Beyond school education, in engineering higher education specifically, one challenge to overcome is the dissociation of practice and education from sustainable development goals, and it has been evidenced that a lack of understanding of sustainability by engineers has negative consequences for the environment, economic growth, and for society. Anholon et al. (2022), for instance, investigate the impacts of unforeseen disruptions, such as COVID-19, citing the lack of understanding of sustainable development goals (SDGs) in engineering education as the main factor limiting their ability to resolve disruptions more effectively. Consequently, transportation and availability of goods are affected because of a lack of focus on social and environmental implications of business activities. This highlights that there are significant barriers when handling disruptions to systems and managing environmental impacts, which may limit the ability of engineers to address the climate crisis and disaster risks [2]. In addition, Lönngren (2019) notes that there is lack of interest to combine sustainable education with engineering education, this time coming from the sustainable education research side. In this analysis, Lönngren (2021) refers to complex sustainability problems as "wicked problems" and notes that vague, inconsistent language negatively affects both discussion at expert levels as well as the dissemination and education of wicked problems [21]. Furthermore, the addition of the emotional factor by Shealy, et al. (2021) makes the educational effort considerably more complex [8]. Although there is reported growing interest in integrating environmental and sustainability education in engineering education from engineering departments, sustainable education actors seem less inclined to take on the contribution primarily based on diverging terminologies and traditional siloed practices in the two disciplines [4,22]. However, the climate crisis presents challenges with a different structure and complexity and requires transformations not only in educational spaces but in wider social spaces, including both individual and collective perceptions of the issue [1].

2.2. Climate Change Education

Despite continued development of scientific knowledge of climate change impacts and drivers, confusion in teaching environmental issues, sustainability, and particularly climate change persists. In effect, educators are required to deliver learning with which they are not familiar. At this stage, the core principles of climate change are comprehensive, and the IPCC provides terminology which is widely agreed upon, such as mitigation and adaptation of climate change [14]. However, existing literature with regards to climate change education suggests that delivery of this content is still in its infancy and continues to be vague [5].

Within school education, the limited subject knowledge of teachers on climate change exacerbates the challenge. Even in the UK, which was the first country to establish a legal framework (The Climate Change Act 2008) relating to climate change [23], teachers report that there is not enough teaching on climate change in UK schools. A YouGov poll asked 352 primary and secondary school teachers whether there should be more or less teaching in UK schools about climate change, to which 29% opted for "much more teaching" and 40% opted for "slightly more teaching". However, 75% of respondents reported that they do not feel that they have received adequate training to educate students on climate change [24]. Rudd (2021) critiques "[o]bviously as scientists we weren't doing a particularly good job at communicating the vital information around climate change" [7] and explains that the development of climate change curricula such as You and CO_2 is both unattended and crucial as we begin to experience climate change impacts more frequently [6]. However, mechanisms to facilitate effective climate change education have been identified within some literature, such as making content personally relevant and meaningful for learners [5].

Studies have found that engineering students do not consider climate change and environmental issues to be relevant to their education and profession, unless their courses include lectures in environmental engineering (i.e., geothermal) or the student is self-motivated. In addition, factors such as family and friends, political affiliations, formal education, and experiences in their formative years in secondary education have been identified to shape student beliefs on climate change [8]. Furthermore, in the United States, the acknowledgement of anthropogenic climate change varies across engineering disciplines, with half of civil engineering students disagreeing with the anthropogenic causes of climate change [9].

2.3. Towards a Better Informed Approach

A range of methodologies can be found in the literature, from student surveys [8–10,25], curriculum analyses, and implementations [3,6,7], to detailed problem analysis within a specific context [1,2,4,5]. Using the wealth of information that the literature provides, current engineering education fails to prepare engineering students to consider climate change in their professional practices while societies expect that engineers are both knowledgeable and able to deal with the aftermath of extreme weather events.

Student surveys in engineering education show the inadequacy of the existing curricula with regards to climate change education [4,8–10]. Meanwhile, "wicked problems" presented in the literature show there is now a critical mass of climate education and sustainable education researchers working on improving the inclusion of climate issues in engineering education. Reflecting on both the use and usefulness of the GETA curriculum key, Macdonald et al. (2018) suggest that time and space is needed for the transformation of a curriculum and the GETA implementation proved to go beyond the curriculum into the teaching and classroom practice [26]. Furthermore, climate change presents a rapidly developing challenge for societies; however, the policy and education responses continue to largely be behind the curve. Climate change education has yet to occupy any significant share of the learning undertaken even in countries with high performing education programmes. However, engineering students of today will be required to address the impacts of climate change throughout the course of their professional lives [27,28]. The only way that this can be addressed with the necessary urgency is to take a well-informed and immediate approach to the inclusion of climate change education within engineering higher education.

2.4. ESD and Engineering Curricula Guidelines

Characteristics of educational action for sustainable development are explicitly outlined in the GETA curriculum key developed in Iceland [3,26], but how does this compare with the engineering curricula delivered in UK higher education? The Engineering Council's provision for the engineer in society curricula as part of the Accreditation for Higher Education Programmes fourth edition (AHEP4), outlines the key education areas and themes for engineering curricula delivered in UK institutions [27]. This is equivalent to the European Accredited Engineer (EUR-ACE®) Framework Standards and Guidelines for accreditation of engineering programmes awarded by the European Network for Accreditation of Engineering Education (ENAEE) [29] or the Accreditation Board for Engineering and Technology (ABET) Engineering Accreditation Commission (EAC) criteria for accrediting engineering programs [30]. AHEP4 presents the latest update of the accreditation requirements for engineering programmes in UK higher education institutions providing a significant update on the previous edition, particularly with regards to sustainability. AHEP4 and the GETA key characteristics are complementary as they prioritise knowledge and social responsibility as well as aligning with the UN SDGs.

The learning objectives (LOs) of the AHEP4 courses are grouped across five engineering-specific areas of learning [27], these are:

- Science and mathematics
- Engineering analysis
- Design and innovation
- The engineer and society

- Engineering practice

The LOs provide the underpinning principles that are critical to becoming a practicing engineering professional. It should be noted that fulfilling the LOs is likely to occur across the course concurrently. Sustainability is one element of the engineer and society learning area, along with ethics, risk, security, and equality diversity and inclusion. Within UK higher education, three-year undergraduate bachelor degrees and one- to two-year masters degrees are the most common qualification acquired on the road to becoming an engineering professional, particularly with chartered status. As masters degrees are more advanced, they have the greatest level of requirements to fulfil in order to meet an LO [27]. The environmental or sustainability LOs for a masters level degree are presented for AHEP3 [31] in comparison to the updated AHEP4 [27] in Figure 3.

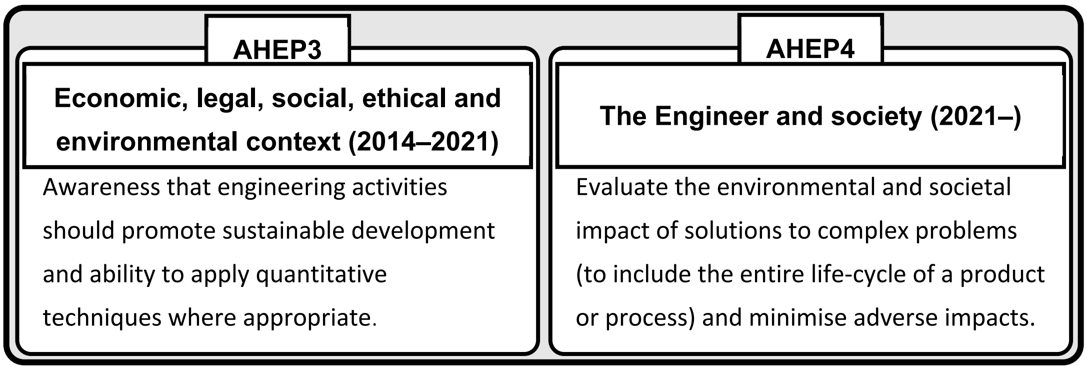

Figure 3. The sustainability learning outcomes from AHEP3 [29] and AHEP4 [27].

Juxtaposed against the third edition, the AHEP4 sustainability guidelines move beyond mere awareness of environmental issues and expect students to be able to evaluate the impact of solutions and minimise adverse impacts [28]. However, the AHEP4 alone does not provide direction on how engineering course materials and assessments can be adjusted to comply with these updates. It calls for higher education professionals to consider the impacts from and to the environment and include them in engineering curricula for the purpose of sustainability and conservation. Sustainability in AHEP4 remains loosely defined, which allows us to smoothly transition from the current to an adjusted curriculum, not deviating from the existing content, rather highlighting the aspects of the environment and climate change more explicitly.

The GETA curriculum key was the culmination of a series of studies between 2007 and 2011 to assess the inclusion of sustainable development (as per the Brundtland report definition [19]) in the curriculum delivered in Icelandic schools over a decade ago. In developing the method for data analysis, the seven characteristics included in the GETA curriculum key were considered for analysis, these are [3]:

1. Indications of values, opinions, and feelings about nature and environment.
2. Identification of knowledge contributing to a sensible use of nature.
3. Statements about welfare and public health.
4. Indications of democracy, participation, and action.
5. Recognition of equality and multicultural issues.
6. Indications of awareness and understanding of global issues.
7. References to economic development and future prospects.

There is substantial overlap between the seven GETA key characteristics and the five learning areas within the engineer and society aspect of AHEP4, as illustrated in Table 1. This is encouraging as it demonstrates that the development of accredited higher education engineering programmes has attempted to capture sustainable elements in line with the UN SDGs. The engineer in society learning areas capture a broader skillset needed by engineering professionals and goes beyond technical expertise. The first area of learning is sustainability (see Figure 3) which corresponds with GETA characteristics 1 and 2. The second area of learning is ethics, which loosely aligns with GETA key characteristics 1, 4, 6, and 7. The third and fourth learning areas can be roughly aligned with GETA key characteristics 2, 3, 6, and 7. Finally, the fifth learning area of equality, diversity, and inclusion maps directly to the fifth GETA key characteristic.

Table 1. Matrix of GETA key and AHEP4 engineer and society learning objectives.

The Engineer and Society / GETA Key	Sustainability	Ethics	Risk	Security	Equality Diversity and Inclusion
1 Environmental Value	✓	✓			
2 Sustainability	✓		✓	✓	
3 Health			✓		
4 Democracy		✓			
5 Equality					✓
6 Global		✓	✓	✓	
7 Economy		✓	✓	✓	

Reviewing the recent literature on both ESD and climate change education resulted in the decision to use the GETA paradigm for the alignment of engineering curricula with climate change education in a pilot study and consequent inclusion of climate-relevant content. Most of the literature cited depicts the status-quo in engineering education both from the perspective of the student as well as from the teacher, and the challenges associated with implementation of ESD. However, AHEP4 outlines the necessary updates in engineering higher education requiring more in-depth knowledge in graduate engineers in relation to society, economy, and the environment. However, there is limited provision for the implementation of these learning objectives within curricula as there is a lack of guidance for educators. Change in engineering is imminent, necessary, and expected, yet not defined. Engineering research, however, is providing climate-related context and the GETA is an example of successful evaluation and implementation within education. Both the AHEP4 and the GETA key consider sustainability broadly, and so it was determined that these approaches could be adapted to shape the inclusion of climate change within the curricula.

3. Methodology

As per the IPCC definitions and the UN SDGs literature, mitigation and adaptation were the key terms for contextualising the analysis under the umbrella term climate change. The analysis, therefore, is based on the overarching context of evaluating references of mitigation (M) and adaptation (A) for climate change (CC) using a novel tool called the MACC evaluation. In order to identify MACC themes within engineering curricula, key terms were identified in order to evaluate the inclusion of climate change. The MACC key terms are outlined in Table 2 alongside their definition and justification for inclusion as a key term within this analysis.

Agreement on MACC key terms of relevance to engineering to be considered in the analysis was agreed early on, which was one of the key mechanisms used to ensure rigour within this qualitative research [32]. Further measures taken are outlined in Table 3.

Table 2. MACC key terms.

Mitigation		
Term	**Definition**	**Justification**
Greenhouse Gases (GHGs)	Gaseous constituents of the atmosphere, both natural and anthropogenic, that absorb and emit radiation [14].	Features in the definition of climate change mitigation [14].
Carbon Emissions	A naturally occurring gas, CO_2 is also a by-product of burning fossil fuels, and is the principal anthropogenic GHG that affects the Earth's radiative balance [14].	Refers to one main GHG and is used interchangeably with GHGs [33].
Whole Life Cycle (WLC) Analysis	WLC analysis considers the impact of a building, structure, or product over its entire life, through design, build, operation, maintenance, demolition, and disposal stages [34].	Featured in AHEP4 sustainability LO [27] and a key mechanism for measuring GHGs [34].
Net Zero	Condition in which anthropogenic emissions are balanced by anthropogenic GHG/carbon removals over a specified period [14].	Key policy strategy to mitigate climate change in the UK (and elsewhere) [33].
Decarbonisation	The removal of emissions from processes and products [33].	Commonly used to refer to the reduction in carbon emissions and other GHGs [33].
Adaptation		
Term	**Definition**	**Justification**
Adaptation Measures	Adaptation measures, options, or actions are steps that can be or have been taken to improve resilience to environmental and climate impacts [14].	Adaptation is the main solution to addressing climate change impacts [12].
Resilience	The capacity of social, economic, and environmental systems to cope with a hazardous event or disturbance, responding in ways that maintain their essential function and structure while also maintaining the capacity for adaptation and transformation [14].	The status of climate change ready systems and infrastructure [35]
Natural Hazards	A potentially damaging physical event that may cause the loss of life or injury, property damage, social and economic disruption, or environmental degradation [18,36].	Common consequences of extreme weather events (i.e., landslides/flooding) [12,37]
Extreme Weather	Weather events that occur rarely normally as rare as or rarer than the 10th or 90th percentile of a probability density function estimated from observations [14].	Extreme weather can have significant impacts and will increase in frequency due to climate change [12]
Risk	The potential for adverse consequences arising from potential impacts of climate change as well as human responses to climate change [14].	Key measure of climate change impacts [37].

Table 3. Measures taken to ensure the rigour of qualitative analysis undertaken. Adapted from [32].

Aspect	Measures Taken
Truth value	Key term definitions established and agreed by research team early on (see Table 2). Key terms considered within the wider context of the MD and LO.
Consistency	Structured analysis clearly outlined. Interpretation of key terms open to researcher bias, so analysis results were moderated by another member of the research team. Differing interpretations were discussed within the research team to achieve consensus.
Applicability	Text analysis of MDs and LOs from programme handbook to enable applicability across engineering modules. Method enables future analysis of other modules within the programme handbook and potentially from other institutions.

The MACC evaluation was structured based on the analysis of engineering curricula across the School of Engineering at a UK higher education provider. The university delivers accredited engineering courses across civil, electrical, and mechanical engineering disciplines, as well as delivering specialist masters programmes, such as road design and railway operations. According to the School of Engineering Annual Report there was a total of 1772 students on taught programmes within the School of Engineering (see Table 4), including the 3 main disciplines and those on the general engineering courses. Students on the general engineering courses participated in a range of modules from across the three main disciplines. All of these courses are delivered or supported by over 190 academic staff [38].

Table 4. School of engineering student numbers [38].

Course	Postgraduate Taught	Undergraduates
Civil Engineering	323	227
Electrical Engineering	246	226
Engineering	38	148
Mechanical Engineering	50	552
Total	729	1043

Across these courses there were 225 modules (the equivalent of courses in other international contexts) in the academic year 2020–2021. The learning objectives outlined in the AHEP4 curriculum for higher education engineering courses are neither siloed to individual modules nor mandatory to be included in every module. Therefore, for the purpose of this evaluation it was not necessary to undertake a review of all modules delivered, which also aligned with the timeframe of the study. Instead, the learning objectives were achieved concurrently across many elements of the taught material delivered and thus, the first stage of the study was to select the modules for analysis and set the criteria for the module selection. The modules evaluated were part of those delivered within engineering; whilst it was possible for engineering undergraduates to take modules beyond this, these are very limited as many optional modules fall within engineering regardless. Furthermore, provision for one MACC-focused module would rely on students actively engaging with the topic [8] and would ensure this topic is siloed rather than embedded across the course.

The selection process sought to identify those modules most likely to include or be relevant to the MACC key terms. The initial module selection criteria are the broad categories of heavy emissions sectors commonly included within engineering disciplines where climate change themes would be relevant. These are:

- Transportation
- Energy

- Materials
- Water, Fluids
- Economy, Management, Technology
- Society, Policy
- Environment
- Professional Skills

At the curriculum review phase, the most effective way to evaluate the inclusion of MACC characteristics is to review the module descriptions (MDs, the equivalent of course syllabi in other international contexts) and the learning objectives (LOs) associated with each module. In these texts, the module lead provides an overview of the content (MD) they intend to deliver and a detailed list of knowledge and skill assessment areas that the student should be competent in by the end of the module (LO). The MD and LO of each module were accessed via the online programmes web directory for the School of Engineering (the equivalent of a course catalogue in other international contexts). As the engineering disciplines are technical and explicit, our hypothesis was that the inclusion of the MACC key terms in the MD and LO would evidence that climate change education was included in the module. Specifically, LOs set the criteria for assessing student knowledge acquisition relevant to the module, therefore it was important to investigate whether climate change-relevant content was included in the proposed assessment content. Critically, in this analysis we therefore interpreted explicit expression as explicit intention to deliver curricula content. This approach enables a consistent method to review content of courses at a high level whilst also considering the key elements of modules delivered. By applying a systematic text analysis of the module overviews from the programme directory, the MACC key terms can be identified and the inclusion of climate change across engineering courses can be quantified.

Following the module selection and text analysis of MACC key terms, the overview of the data led to the observation that MACC key terms were referred to at a very low frequency, motivating the research team to consider a third level of analysis: the conceptualisation of integration of MACC key terms. To this end, a third tier of analysis was introduced to support the integration of MACC across curricula. The analysis evolved from a tiered evaluation, progressing from criteria-based selection to text analysis and MACC key term integration. The MACC terms integration was undertaken in the format of a series of suggestions to demonstrate the potential inclusion of MAC terms. The suggestions were made by the research team and MACC key terms were added in the MDs or LOs or both for most of the 45 selected modules (43 out of the 45). As engineering education is designed to endow students with knowledge and practical skills concurrently, the insertion of terms was undertaken with the same philosophy, namely aiming for high frequency of MACC term insertion across modules rather than a high volume of terms in a few modules. An overview of the method is shown in Figure 4.

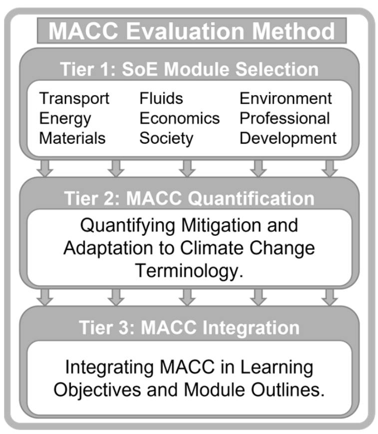

Figure 4. MACC evaluation method: overview of the three tiers of analysis.

4. Results

4.1. Tier 1 Module Selection

The MACC evaluation tool outlined in the previous section was applied to the School of Engineering taught undergraduate and masters level programmes for the academic year 2020–2021. There are three distinct curricula in the School of Engineering: civil engineering, mechanical engineering, and electronic and electric systems engineering (referred to as electrical engineering from this point) and the modules were retrieved from all of them. Separately, the Department of Civil Engineering listed 102 modules, the Department of Electrical Engineering listed 81 modules, the Department of Mechanical Engineering listed 47 modules, and collectively five of those were shared among disciplines, so they were double entries and removed from the final count as shown in Table 5. A total of 225 modules were initially considered for analysis, and this was reduced to 45 modules which met the inclusion criteria following the first tier of the evaluation. Representing 20% of all the modules delivered, this sample was considered suitably large for further analysis. Furthermore, Table 6 shows the number of modules attributed to each of the selection criteria for the initial Tier 1 module selection. It should be noted that many modules were eligible for more than one of the inclusion criteria. The proportion of modules related to each of the Tier 1 selection criteria ranges from 20% for modules related to fluids or water, whilst economy management technology relates to nearly 70% of the modules selected.

Table 5. Proportion of modules selected per engineering discipline.

Engineering Department	Total Number of Modules	Number of Modules Selected	Percentage of Total Modules
Civil	102	29	28.4%
Electrical	81	9	11.1%
Mechanical	47	7	14.9%
Common Modules	- 5	-	-
School of Engineering	225	45	20.0%

Table 6. Percentages of modules per selection criteria in Tier 1.

Tier 1 Selection Criteria	Number of Modules	Percentage of Selected Modules
Transport (rail/road)	18	40%
Energy	16	36%
Materials (waste, natural resources)	18	40%
Water/Fluids	9	20%
Economy Management Technology	30	67%
Society/Policy	12	27%
Environment	15	33%
Professional Skills	18	40%

4.2. Tier 2 MACC Analysis

Following the selection of modules, the LOs and MDs were analysed for the inclusion of MACC key terms as listed previously in Table 2. A total of three instances of MACC key terms were identified across the 45 modules analysed, as shown in Table 7. The Tier 2 analysis identified one reference that implied a whole life cycle (assessment was inferred), one reference to risk in the context of climate change, and one reference to adaptation to natural hazards. However, the concept of climate change was not suggested in any of the modules. These instances are shown in Table 8.

Table 7. MACC key terms identified in Tier 2.

Mitigation Vocabulary	Number of Modules	Percentage of Modules
Greenhouse Gases (GHGs)	0	0%
Carbon emissions	0	0%
Whole Life Cycle Analysis (WLCA)	1	2%
Net Zero Emissions	0	0%
Decarbonisation	0	0%
Adaptation Vocabulary	**Number of Modules**	**Percentage of Modules**
Resilience	0	0%
Risk	1	2%
Extreme Weather	0	0%
Natural Hazards	1	2%
Adaptation Measures	0	0%

Table 8. Mitigation or adaptation terms found in Tier 2.

Module	Tier 1 Selection Criteria	Mitigation Key Terms	Adaptation Key Terms	MACC Text in MD	MACC Text in LO
CIV-02	Transport Economic Technology	-	Risk	Technology decisions that require ... safety and risk management	Apply principles of technical and project risk management
CIV-07	Economic	Whole Life Cycle Assessment	-	Decisions on construction life cycle to evaluate the environmental and sustainability performance	Describe the implications of the construction life cycle
CIV-18	Fluids	-	Natural Hazards	Flows of environmental and engineering relevance such as lakes	Understand the conservation of ... energy of engineering/environmental interest Explain the main implications of environmental equilibrium

All sustainability-related modules were included in the analysis; however, as the focus was on climate-related content with a specific term search, most of the sustainability modules were not marked up in the analysis with the MACC terms. To best collect and represent the data, a matrix was devised to record both quantitative and qualitative data. The quantitative data consisted of a list of vocabulary items observed in the MDs and LOs and tick boxes, and the qualitative data consisted of short commentary and sentences from the texts that included either the word items or a similar description of MACC key terms. It is obvious from the terms in Table 8 that even when climate-related terms were used, they were vague and not conducive to building enough concurrent and relevant content to help students understand climate change and how it is related to the engineering profession. For example, whilst the term "risk" was present it had no direct relation to climate change but instead was used more generally. As pointed out in the literature and methodology, the challenges within the climate and environment discourse have been shifting from sustainability to climate change education. Climate change and its study focuses on the interrelated effects of human activity and climatic changes with specific and pinpointed references that reflect the local challenges resulting from the global phenomenon.

4.3. Tier 3 MACC Integration and Re-Evaluation

To complement the Tier 2 text analysis, Tier 3 enables the integration of MACC terminology within the analysed text. The insertion of MACC terminology is based on the criteria for selection of the previous two tiers, as previously outlined in Table 2. In a more comprehensive analysis than the evaluation presented here, an ethnographic approach would be used, namely with the engagement of module leaders to facilitate the accurate insertion of MACC terminology across curricula. However, as this was a pilot study, the insertion of the MACC terms was actioned by the researchers. Following the insertion of MACC terms, the text analysis was repeated to quantify the improvement, the results of which are shown in Table 9.

Table 9. Tier 3 MACC key terms evaluation and integration results.

Mitigation					
MCC Criteria	**Tier 2 Total**	**Tier 3 Total**	**Increase**	**MCC Potential of Sample**	**Total MCC Potential**
Greenhouse Gases (GHGs)	0	19	+19	42%	8.4%
Carbon emissions	0	23	+23	51%	10.2%
Whole Life Cycle Analysis (WLCA)	1	21	+20	47%	9.3%
Net Zero Emissions	0	13	+13	29%	5.8%
Decarbonisation	0	21	+21	47%	9.3%
Adaptation					
ACC Criteria	**Tier 2 Total**	**Tier 3 Total**	**Increase**	**ACC Potential of Sample**	**Total ACC Potential**
Resilience	0	28	+28	62%	12.4%
Risk	1	26	+25	58%	11.6%
Extreme Weather	0	24	+24	53%	10.7%
Natural Hazards	0	28	+28	62%	12.4%
Adaptation Measures	1	34	+33	76%	15.1%

As can be seen in Table 9, the majority of modules could include key MACC terms in the MD or LO. These results demonstrate a significant increase in the inclusion of MACC key terms is possible for the subset of modules that were evaluated in detail. Table 10 shows some examples of text integration in modules from the three disciplines.

Table 10 demonstrates a few examples of text insertion (**bold text**) in the existing module descriptions and learning outcomes from the selected 45 modules in the first tier of the MACC evaluation and analysis. As the selected modules reflected the most energy- and material-consuming engineering fields, insertion of MACC terms was feasible both in the MD and the LO of the modules. However, there were modules where MACC terms were inserted only in MDs or LOs, rather than in both. The process of module adjustment in Tier 3 overwhelmingly showed that if MACC terms could fit in a module description, at least one relevant learning outcome could be drawn from that content. The modules where learning outcomes were added without changes in the module descriptions were the seven modules that already had environmental references—either sustainability or geotechnical elements. The observation from those environment-relevant modules was that the lack of MACC terms corroborated with the existing literature of out-of-date references more relevant to the 70s and 80s environmental education approaches, with the additional observation that the existing references were vague and did not provide enough context—and perhaps even content knowledge—to frame the issues of climate change and the effect it has on engineering professional standards.

Table 10. Tier 3: Integration of MACC terms in MDs and LOs.

Module	Module Descriptions	Learning Outcomes
Civ-09	Standards, sustainability, **and climate change mitigation** issues to be addressed throughout the teaching of this module.	Evaluate materials in terms of cost effectiveness, environmental impact **(e.g., carbon emissions),** and **long-term** sustainability **using whole life cycle assessments.**
CIV-23	(3) Introduction to types of geotextiles; their structure and applications; filtration; drainage; separation; soil reinforcement; **applications to increase earthwork resilience and adapt to climate change**.	**Assess slope performance under different precipitation scenarios and conduct a climate risk assessment.**
EESE-01	This module is about different options which are available for traction packages **including low carbon traction options to promote decarbonisation of the rail industry**.	Demonstrate an awareness of the impact of traction drives on energy use in trains **and how different traction options can support climate change mitigation and net-zero agendas**.
EESE-08	Understand the physics of radio wave propagation at a number of frequency bands **and environmental conditions.**	Discuss recent research results in this topic area **and the impact of climate change on radio wave propagation prediction models as a result of increased frequency of extreme weather.**
MECH-01	The module introduces renewable energy systems including wind energy, nuclear energy, and solar energy **and their role in decarbonisation, reducing GHGs/carbon emissions, and achieving net-zero goals. We will consider the whole LCA of renewable energy technologies to promote sustainable energy systems and mitigate climate change.**	Understanding of the requirement for engineering activities to promote sustainable development and ability to apply quantitative **WLCA** techniques where appropriate, **to consider the costs and benefits associated with climate change mitigation and the resilience of renewable energy systems.**
MECH-07	The content will be presented by a series of lectures presenting case studies accompanied by a number of web-based tutorial sheets and/or additional reading materials to enable students to think about mechanical engineering in the broadest sense **and applied within the context of current real-world challenges, such as climate change.**	Demonstrate an understanding of concepts from a range of areas, including some **typically** outside engineering, **such as climate change mitigation**, and the ability to apply them effectively in engineering projects. Demonstrate a thorough understanding of current practice and its limitations, **particularly with regards to climate change mitigation and adaptation to resilience.**

5. Discussion

The results present the application of the MACC evaluation to a curricula evaluation case study within the context of engineering higher education for the academic year 2020/21. The university is currently transitioning to a sustainable development curriculum across all colleges, hence this evaluation is timely to further encourage an awareness of MACC themes within the wider scope of sustainability. Focusing more broadly on engineering education and the integration of climate-related content, the literature review highlights the barriers to embedding sustainability and climate change within education, particularly in engineering, as well as the need for inclusion of climate change to be addressed. As engineering curricula have been updated since 2020/21, a new evaluation would likely yield more favourable results and the MACC evaluation could be used for better informed content and as a check point by the lecturing faculty. The literature surrounding primary and secondary school education provided insights to the challenges that teaching professionals face. Barriers cited include scarcity of teaching resources, lack of training, lack of experience, and lack of confidence, whilst supporting structures were mostly underprepared if present at all.

In contrast, some academics within engineering will have a relatively high level of understanding of MACC themes due to their involvement in research. Familiarity with climate change themes was a benefit of the case study university and utilising this expertise informed the development of the methodology. The case study team was made up of the Deputy Director of Education of the College of Engineering and Physical Sciences, the

Director of Education in the Railway Research and Education Centre, an associate professor with expertise in green infrastructure, a research fellow with expertise in adaptation, and a research associate with expertise in the intersection of science and sustainable education. The team also faced some of the challenges mentioned in the literature, for instance agreeing on a single shared understanding of terms, bridging education and engineering research disciplines, and consequently negotiating the MACC key terms as different disciplines put emphasis on different terms. In addition, local anecdotal data from internal departmental communication revealed that other staff were either not clear on the definitions of adaptation and mitigation or did not approach the terms with widely agreed definitions, as reflected in the literature [22]. The lesson learned from Lönngren and van Poeck (2021) is that clarity of terms provides accuracy and limits misinterpretations that could make the teaching of this particularly complex subject matter difficult to comprehend and inhibit students from efficient knowledge acquisition. Unclear terminology in climate change education could cause considerable hindrance to inclusion of climate-related content and care must be given to terms detailing the making of a reformed, accreditation-ready curriculum. Despite these differences, MACC themes were found to be largely absent in higher education.

5.1. Discussion of MACC Evaluation Results

The MACC evaluation utilises three tiers of selection, analysis, and integration to support the identification and embedding of climate change themes. In this article, the results of a curriculum analysis are presented, demonstrating how the MACC evaluation can be practicably applied to improve climate change capability across activities, individuals, and organisations.

The initial selection of modules in Tier 1 of the evaluation used common areas across sectors where climate change is a topic of rapid development. The Tier 1 categorisation of modules was a necessary step to provide a coherent and unified conceptual frame for the data collection and analysis. The topics were widely reflected across the modules selected for evaluation enabling a targeted evaluation of the inclusion of MACC key terms in later tiers of the evaluation. Whilst the modules were concerned with this wide array of selection criteria, there was a significant difference in the number of modules that were identified across the different engineering disciplines. From a total of 225 modules included in the 2020–2021 School of Engineering curricula, 125 modules are delivered at masters level, providing engineering graduates with a wide variety of specialisations. As a result, the majority of selected modules in the study were masters modules (26 of the 45). This occurrence is partly due to the fact that the three-year courses start from basic understanding of the engineering disciplines, and in the second (intermediate stage) and third years, students delve into learning specific engineering practices and their applications. Masters courses offer niche specialisations, which is a step further than the three-year courses. Honours modules that belong to the four-year undergraduate courses are often similar to the masters modules. This also offers an insight on why the civil modules make up the biggest curriculum. Many of the specialties offered at the masters level require a versatility that often stems from the civil course. Although the masters courses do not exclude mechanical or electrical graduates, the content is more closely related to the civil curriculum and therefore attached to it.

The MACC terminology presented previously in Table 2, establishes a foundational and comprehensive basis upon which a MACC evaluation can be undertaken. In the case presented in this article, MACC key terms were identified through the text analysis of School of Engineering modules, conducted as part of Tier 2 of the evaluation. However, the evaluation identified very limited coverage of the key terms across the engineering curricula assessed. This indicates that engineering graduates are sorely underprepared with regards to addressing climate change challenges within their professional careers at the point where they enter the job market. Furthermore, they are not prepared to address other severe disruptions to society, infrastructure, and systems [5]. The findings from the

Tier 2 analysis further evidence the dissociation of engineering education to climate-related content. This observation confirmed survey findings in the literature [2,8–10,25] as well as the well-timed educational reform for the engineering curricula with positive references evidenced in the existing climate change education literature [5,7,11].

It was observed that MACC key terms were also missing in modules with content knowledge explicitly about reducing carbon emissions or mitigating sourcing of raw materials. A key observation that was recorded before the selection stage was the number of modules across the three curricula that referred to natural capital and its relation to the engineering profession. The total number of modules with environmental references was seven, four of which were sustainability modules. The environmental references in the sustainability modules were examples of sustainable applications in construction and transportation and included exercises to emulate those examples, with no reference to mitigation, adaptation, climate change, or the motivation for sustainability. The three other modules were related to using natural capital mostly for water drainage and referred loosely to fluid flow with little to no reference to flooding, or the frequency of engineering intervention when adverse weather phenomena occurred. It is possible that the lecturers included MACC references in their lectures, but these were not reflected in the MDs or the LOs. Emphasis is put on the absence of LOs that were relevant to MACC, because at the assessment and feedback stage the budding engineer is called to demonstrate the development of their competencies in practicing the profession.

The MACC evaluation further supports users to not only evaluate documents, policy, or in this case curricula, it also facilitates reflection and implementation by creating a framework to embed MACC key terms within the studied documents and practices. The Tier 3 analysis consisted of qualitative suggestions to integrate MACC key terms in the context of the existing module descriptions and learning objectives. The third tier of analysis also provided the necessary narratives that clearly differentiated mitigation from adaptation, which was an added benefit from the qualitative aspect of the study. In the case study undertaken, most modules were found to be relevant to terms relating to both mitigation and adaptation. Some modules were only linked to either mitigation or adaptation. In the Tier 3 analysis, all the MACC key term percentages increased by over 40% except for net zero as shown in Table 9. The most frequent MACC term inserted in the module descriptions and learning outcomes was adaptation measures, which aligns with the fact that adaptation of current practices is necessary to achieve the net zero targets.

The case study presents a clear vision of systemic and systematic change; systematic as it is consistent across all modules included in the sample, and systemic because it proposes a paradigm shift towards climate change-centered education in engineering. This further supports the objectives of the university to develop a smart and sustainable campus, with sustainable development featured across degree courses in all subjects [39]. By extension of the university sustainability objectives, further embedding MACC themes across engineering curricula will support a faster and more effective transition to a sustainable and climate resilient campus and wider institutional practices. This process could be further expediated by applying the MACC evaluation across all courses regardless of discipline.

5.2. Approach and Limitations

This article has demonstrated how the MACC evaluation that was developed provides a robust methodology to structure evaluation of MACC key terms alongside a case study evaluation of engineering curricula. The MACC evaluation facilitates a tiered analysis providing sufficient flexibility, such that this approach may be applied to other higher education disciplines, different levels of education, or indeed other contexts, i.e., policy document evaluation. However, the needs of other environments should be considered before application of the approach to ensure that it retains its efficacy.

The analysis presented here was undertaken on module descriptions for the courses run in the 2020–2021 academic year; consequently, they were reflective of the AHEP3 curricula for accreditation outlined by the Engineering Council [31]. The results presented may not be reflective of the curricula in their present form where AHEP4 has been implemented. However, the tool developed is equally applicable for evaluation of present courses and the results from this case study provide an initial benchmark, such that future analysis may reflect the progression of curricula.

Furthermore, this analysis is a case study as the research team accessed one school in one university in the UK. However, as the university delivers engineering courses that are accredited by the Engineering Council, it is expected that these results will be relatively representative of the results that could be expected if the MACC evaluation were applied to the engineering curricula in other UK higher education institutions. The study outcomes regarding the current climate change capability in UK higher education provides ample opportunity for curricular reform that can instill aspirations for both current and future undergraduates to enter the profession skilled and able to address the climate crisis.

5.3. Action for Further Research and Implementation

Moving forward, utilising automated techniques could extend the capability of the MACC evaluation to facilitate evaluation of large volumes of selected materials and enable application in other types of documentation. Automation would also greatly benefit curricula analysis as it would enable a more detailed analysis of taught materials beyond the module description and the learning objectives. The key barrier to extending the application of the tool further for curricula evaluation is that there is a broad range of materials to which this approach could be applied. For example, it would be challenging to prepare curricula materials, reference texts, and tutorial materials in a consistent and compatible format to the tool. However, the learning objectives and module descriptions capture the core elements of the modules and consequently, if climate change were embedded, this analysis would have identified this.

If the MACC tool were used for an extended evaluation of all engineering modules, other courses, or other institutions, an automated process would also provide greater flexibility to widen the MACC terminology informing the evaluation. This kind of rapid evaluation would prove beneficial for any further evaluation of MACC terminology in a wide variety of contexts, and consequently, its development provides a significant step forward in this area. The text analysis that was undertaken in this research focused on the module descriptions and learning objectives of 45 modules delivered within the engineering curricula at one higher education institution. In future work, application of the MACC evaluation across multiple UK higher education institutions would be insightful validation of the method developed.

Tier 3 of the MACC evaluation tool demonstrates that it is possible to embed MACC within the engineering module description and learning objectives. However, to address the climate crisis, climate change skills need to be embedded across all areas of the practical and theoretical studies of the graduating professionals [11]. Hindley (2022) and Shealy et al. (2019) specifically identify the impact of attitudes, lived experiences, and feelings, as well as the challenges of integrating climate change education in higher education as being partly an attitude problem. On the one hand, higher education lecturers and teaching actors know they now must have these climate-related discussions, on the other, there is resistance at the level of action that may well be attributed to personal attitude [11,25].

6. Conclusions and Forward Look

Looking forward and following the philosophy of the UN SDGs, climate change education should be approached with a climate-related attitude at institutional level, in essence an institutional attitude change. In the case study of engineering in higher education, the transition to a sustainable campus is a step forward which could be accelerated further with a broader culture change that reflects climate-action-based values. Values are the two points of the GETA group that were not included in this study, (1) indications of values, opinions, and feelings about nature and the environment, and (4) indications of democracy, participation, and action—the learned lesson is lecturers that hold climate change values in their profession are more likely to teach climate-related content more effectively and successfully. Both values (1 and 4) included in the GETA curriculum key and the UN SDGs call for root action in the beliefs, behaviours, and attitudes of people and institutions. A call for change at an institutional level is a call for a collective shift in attention to the current climatic reality and to take collective action.

The findings of the case presented here provide the evidence that action is urgently needed to prepare engineering graduates for professions in an uncertain climate. The MACC tool evaluation is only the first step in addressing this challenge based on valuable insights from the existing literature. Moving forward, action is needed to embed MACC key terms across the School of Engineering curricula, firstly in module descriptions and learning objectives and then within the taught materials delivered. However, to undertake this, educators may need support to implement MACC themes across their taught content, and the experience of cross-sectional, interdisciplinary collaboration can be the key to swift and robust integration and implementation. As climate change is a dynamic and evolving challenge and area of research, it is critical that the MACC tool is revisited to further evaluate the implementation of MACC terminology within higher education. The flexibility of the MACC tool design allows also for the adjustment of MACC terminology as per the updated climate science literatures, and an automated tool would ensure that adjustments and changes are undertaken efficiently.

Finally, once higher education establishes a maturity of skills across graduate engineering cohorts and the delivery of MACC themes within engineering courses becomes more commonplace and sophisticated, it would be prudent to identify any remaining skills gaps across industry. This will further inform and hone the knowledge and skills with which engineers are equipped at degree level. Whilst higher education is the first stage in an engineer's professional development, it is one stage of many in their career and only one opportunity to learn. Engineering education is the formative development of professional skills; however, to be an engineer is to continue to develop throughout their professional life and to focus that advancement on addressing the needs of society. For this reason, it is critical that MACC remains a central theme in this training as the climate crisis continues to develop.

Author Contributions: Conceptualization, P.A., R.S.F., E.J.S.F., H.J.F. and A.D.Q.; Methodology, P.A., R.S.F. and A.D.Q.; Formal analysis, P.A. and R.S.F.; Investigation, P.A. and R.S.F.; Data curation, P.A. and R.S.F.; Writing—original draft, P.A. and R.S.F.; Writing—review & editing, P.A., R.S.F., E.J.S.F. and A.D.Q.; Supervision, R.S.F. and A.D.Q.; Project administration, R.S.F.; Funding acquisition, H.J.F. All authors have read and agreed to the published version of the manuscript.

Funding: Rachel S. Fisher's time on this research was in part funded by NERC grant NE/X001938/1.

Institutional Review Board Statement: Not applicable.

Informed Consent Statement: Not applicable.

Data Availability Statement: No new data were created or analyzed in this study. Data sharing is not applicable to this article.

Conflicts of Interest: The authors declare no conflict of interest.

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