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SUSTAINABLE ENGINEERING EDUCATION IN RESEARCH AND PRACTICE

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ABSTRACT

Sustainability and responsible use of the resources at our disposal are among the most important goals of our time. Employees are looking for next-generation employees with ever more skills. To ideally foster these in engineering and prepare them for future challenges, the integration of education for sustainable development (ESD) with a linkage of technical and sustainability-oriented issues in the curriculum is essential. This paper takes up two points: Firstly, an analysis of the research landscape in Engineering Education Research (EER) on the topic of "sustainability" is undertaken. For this purpose, more than 3500 conference papers of EDUCON and FIE of the years 2014 to 2018 as well as 2021 (EDUCON only) are evaluated. The methodology of the analysis as well as the set of main and sub categories (among them "sustainability") will be presented at SEFI 2022. The results of the analysis of the research landscape show that the topic of sustainability has so far played a negligible role in the conference contributions. Secondly, the focus is on the implementation process and the linking of technical and sustainability-oriented issues. The study programme concept of the Leuphana University offers two options for sustainable technical education by combining major and minor study programmes. The interdisciplinary combinations are presented and explained using module examples. In total, this paper provides a research-based contribution to sustainable engineering education in research and practice.

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1 INTRODUCTION

Sustainability and responsible use of the resources at our disposal are among the most important goals of our time. Employees are looking for next-generation employees with ever more skills. In order to optimally promote these in engineering and prepare them for future challenges, the integration of education for sustainable development (ESD) with a linking of technical and sustainability-oriented topics in the curriculum is essential. Worldwide, studies show that the topic of sustainability is insufficiently addressed in engineering curricula [1-4]. For example, the study by [1] assesses the Nigerian engineering curriculum and shows that sustainability dimensions are poorly included, with environmental concepts mentioned most frequently and social issues least frequently. An analysis of the presence of sustainability issues in 16 Spanish higher education curricula in education and engineering show that they are more homogeneously represented in education curricula than in engineering curricula [2]. A survey of students in the Civil and Environmental Engineering (CEE) programme at the Georgia Institute of Technology investigated students' interest, knowledge and experience in sustainability. The results show that students are interested in sustainable development, but there is still potential to improve sustainability education [3]. An investigation of the integration of social sustainability into engineering education at the Royal Institute of Technology (KTH) in Sweden based on interviews and indicates that curriculum managers and teachers at KTH have difficulties understanding the concept of social sustainability [4]. Other studies show positive developments in relation to sustainability [5-6]. An analysis of the current state of Australian universities shows that a large proportion have successfully introduced sustainable engineering education, while the rest are currently focusing on integrating it into their curricula [5]. In addition, [6] describe the progress made over the last 25 years in incorporating sustainability and green engineering content into chemical engineering curricula.

The above analyses and studies show that there are some universities that have mastered the challenges and are well on their way to implementing education for sustainable development in engineering. However, a majority of the studies show that sustainability aspects are strongly neglected in engineering education, especially social sustainability aspects. Which is where this contribution intervenes. An analysis is made of the research landscape in engineering education research (EER) on the topic of "sustainability". For this purpose, 3570 conference papers of EDUCON and FIE from 2014 to 2018 and 2021 (EDUCON only) are analysed. The methodology of the analysis will be described in the following section. **Sec. 3** presents the evaluation with a focus on the issue of sustainability. Furthermore, the focus is on the implementation process and the linking of technical and sustainability-oriented questions. Therefore, the last **sec. 4** shows a successful implementation of sustainable engineering education. By the study programme concept of Leuphana University with the combination of major and minor study programmes, two options for a sustainable technical education are presented.

2 METHODOLOGY

The systematisation of the EER landscape is carried out as design-based research work, e.g. [7-8], which contributes to theory building by providing a categorisation of the international research field, but also leads to the structuring and bundling of research findings in practical application. For the purpose of gaining knowledge at the interface of engineering and sustainability, two leading IEEE conferences of the international EER research landscape, the FIE and EDUCON, were selected as the basis for the systematisation, whose publications appear annually in a two-stage blind review process. With the aim of an international and up-to-date analysis, contributions to EDUCON and FIE from the years 2014 to 2018 and 2021 (EDUCON only) were systematically analysed and categorised using a catalogue of categories developed in advance. In doing so, EDUCON, like SEFI Annual conferences, focuses more on the European research landscape, while FIE expands the research work to include a more international (especially American) view. This approach addresses the critiques of Williams and Wankat [9], Williams et al. [10] as well as Borrego and Bernhard [11], who point to existing disciplinary and geographical divisions in the research landscape. Although the research presented does not provide a complete overview, basic statements and research trends on sustainable engineering education can be derived. The number of articles from the respective years that were used to categorise the scientific articles is presented in **Table 1**.

Table 1. *Number of published and categorised papers of the international EER conferences Global Engineering Education Conference (EDUCON) and Frontiers in Education Conference (FIE) in the years 2014 - 2021, own data.*

Year	EDUCON	FIE	Total
2014	196	519	715
2015	154	403	557
2016	191	410	601
2017	289	306	595
2018	300	537	837
2021	265	-	265
Total number of categorised paper			**3570**

2.1 Methodological procedure, implementation and critical reflection

In the content-structured procedure according to [12], the categories for the systematisation of the EER research field were developed inductively from contributions of the EDUCON and the FIE of the years 2014 to 2018. The methodological design of the systematisation and selected partial findings were put up for discussion within the research community [13-14]. The result is a research-guided category system consisting of ten main categories and 78 subcategories, which encompasses the main aspects of the research field, their specification and the relations and delimitations of the individual categories to each other (exemplified with a focus on sustainability in **sec. 2.2**). To increase the quality of the research process and to minimise the subjectivity of the analysis, intersubjective validation

was used consistently from the beginning of the research process. In order to check the uniform understanding, several papers were randomly selected from the total amount of contributions, individually categorised by at least two people and the categorisation subsequently discussed in the team. The discourse about the individual perspectives and the achievement of a consensus in the categorisation led to a secure handling of the category system and consequently to a reliability of the categorisation within the research team. Subsequently, 3570 contributions were systematically analysed and categorised using the category catalogue developed and are available as an Excel list. The topic of "Sustainability" is represented as a sub-category in the category system. For a more in-depth analysis, a keyword analysis within the Excel file was used in the submitted contribution. This in-depth analysis followed the procedures for systematic literature review regarding engineering education research, e.g. [11]. The titles, keywords and abstracts of the papers were searched for the keywords: "sustainability", "sustainable" and "climate change". The results of this extended analysis have been incorporated into the evaluation in **sec. 3**.

2.2 Theory-based positioning of sustainability in the EER landscape

The category system developed consists of ten main categories with up to 12 subcategories each, extracts of which are shown in **Table 2**. In addition to the categories, there are coding rules that describe the assignment criteria for the respective category and add concrete anchor examples or demarcation notes to other categories. For example, the publications sorted into the main category "Teaching and Learning" focus on the teaching-learning process and its design. The category "Topics related to Engineering" categorises publications that place the thematic focus on topics that are not subject-specific but are related to engineering content. One of the subcategories belonging to this main category is "Sustainability" (see **Table 2**). Each contribution was assigned to at least one and at most two main categories. The selection of two main categories ensures that interdisciplinary contributions and contributions that form a transfer between individual topics can also be considered in two different categories. One suitable sub-category can be selected for each main category.

Table 2. *Main categories and exemplary subcategories of the category system for systematising the EER landscape, own data.*

Main categories	
Assessment and Evaluation	**Student Motivation and Decision Making**
Curriculum Design	**Target Group Related Issues**
Discipline Specific Issues	**Teaching and Learning**
Diversity in STEM Fields	**Topics related to Engineering**
Research	**Digitalization**

Sub categories of the main category "Topics related to Engineering"	
• Language Issues • Philosophy in Engineering • Professional Ethics • Professional Skills • Entrepreneurship	• **Sustainability** • International • Academic Writing Skills • Interdisciplinarity & Education

The categorisation carried out according to the systematic and rule-guided procedure described above made it possible to examine the location of sustainability in the area of EER, and the results are presented below.

3 FINDINGS WITH A FOCUS ON SUSTAINABILITY

3.1 General statements of the overall evaluation

The total of 3570 FIE and EDUCON conference articles from 2014-18 and 2021 (EDUCON only) were each assigned a minimum of one and a maximum of two main and sub-categories. A total of 6627 categories were assigned. What is noticeable in the overview of the results of the category allocation is the lower number of allocations in the contributions to EDUCON, which can be attributed to the different absolute number of contributions to the respective conference (see **Table 1**). In both conferences, topics in the context of teaching and learning processes (main category "Teaching and Learning") were addressed most frequently by far. Articles dealing with project and problem-based learning were particularly prominent. Many of the contributions at both conferences also focus on issues and topics of a specific engineering discipline (main category "Discipline Specific Issues") or deal with the development, expansion or re-design of modules or entire curricula (main category "Curriculum Design") in the field of engineering. For limited reasons, a more comprehensive overall evaluation is not included in this paper, as the focus is on the evaluation of the topic area of sustainability.

3.2 Results with focus on the subcategory sustainability

As previously pointed out in the introduction, many educational institutions are lacking a reference to the topic of sustainability and thus to education for sustainable development. In the following, the number of contributions dealing with the topic of "sustainability" will be examined.

Fig. 1 gives an overview of the categorisations of the articles of the FIE and EDUCON to the sub-category sustainability over the years. Out of a total of 6627 categorisations, 48 (0.72%) were made in the sub-category "Sustainability". By way of explanation, it should be added that a category is only awarded if the *majority of the contribution* deals with the theme. Most articles mentioning sustainability issues were identified in 2017. In general, the proportion of articles that address the topic of sustainability is extremely low at 0.72%, which illustrates and supports the situation described in the introduction. Contrary to expectations, there is no trend to be noted in the results.

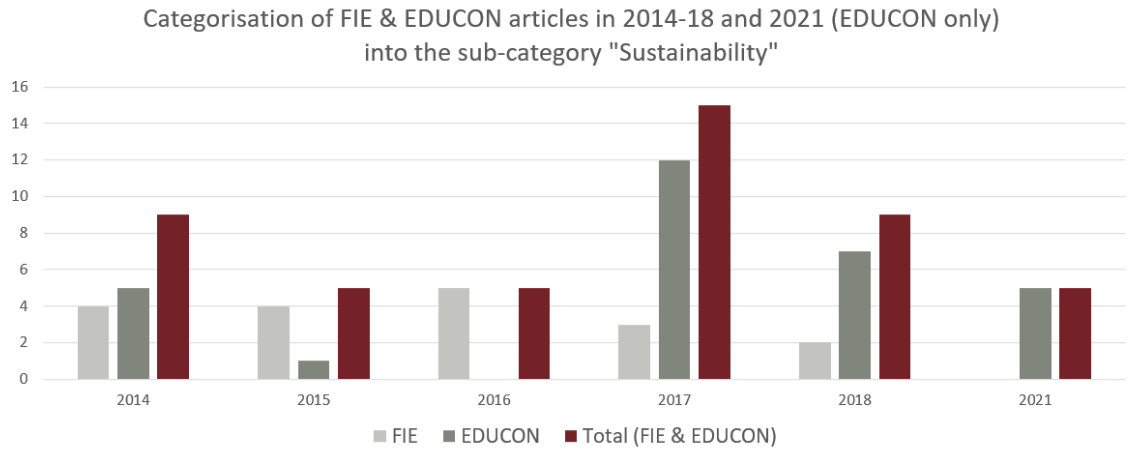

Fig. 1. *Categorisation of FIE & EDUCON conference articles in 2014-18 and 2021 (EDUCON only) into the sub-category "Sustainability", own data.*

In order to find out whether the topic of sustainability nevertheless plays a role in the categorised articles, a "COUNT IF" query was carried out in Excel. It was analysed how often the word "sustainability" was written in the title (9 times), in the keywords (20 times) and in the abstract (39 times). In addition, the words "sustainable" and "climate change" were filtered. The word "sustainable" appeared in a total of 18 out of 3570 titles, in 17 keywords and 55 abstracts. "Climate Change", on the other hand, was only mentioned once in the title and keywords and 3 times in the abstract. The occurrence of the word "sustainable" should be interpreted with caution, as it refers not only to sustainability aspects, but also, for example, to long-lasting projects that do not directly include sustainability issues. With a total of only 5 mentions, the occurrence of the word "climate change" can be neglected. **Fig. 2** shows the frequency of the word "sustainability" in the title, abstract and keywords depending on the year.

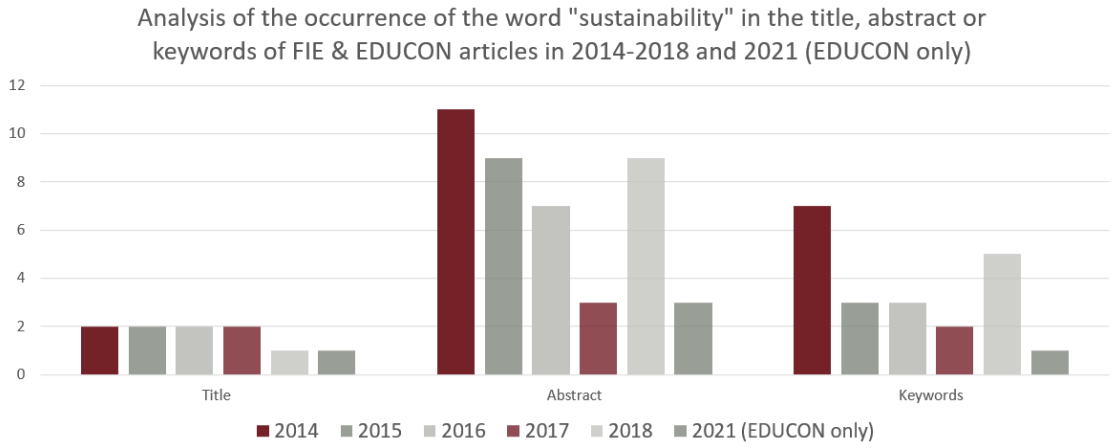

Fig. 2. *Analysis of the occurrence of the word "sustainability" in the title, abstract or keywords on FIE & EDUCON conference articles in 2014-18 and 2021 (EDUCON only), own data.*

The latter analysis confirms the results of the categorisation, as the frequency of the keywords is in similar dimensions to the allocation of the articles. Basically, however, it becomes apparent that very little relevance is attributed to the topic of sustainability in engineering education research and practice, which urgently needs to be changed. An approach for integrating sustainability aspects in engineering education is therefore presented in the following chapter.

4 INNOVATIVE TEACHING CONCEPT FOR SUSTAINABLE ENGINEERING EDUCATION PRACTICE

The interdisciplinary study model of Leuphana University provides a successful framework for the curricular connection between technology and sustainability. The individual study program is created from Leuphana first semester (30 CP), major (90 CP), minor (30 CP) and complementary studies (30 CP). Students even have the opportunity to customize their study focus and to freely combine their major and minor subjects. For the realisation of a sustainable engineering education, there are two possible combinations with different weighting of the technology and sustainability components, see **Fig. 3**.

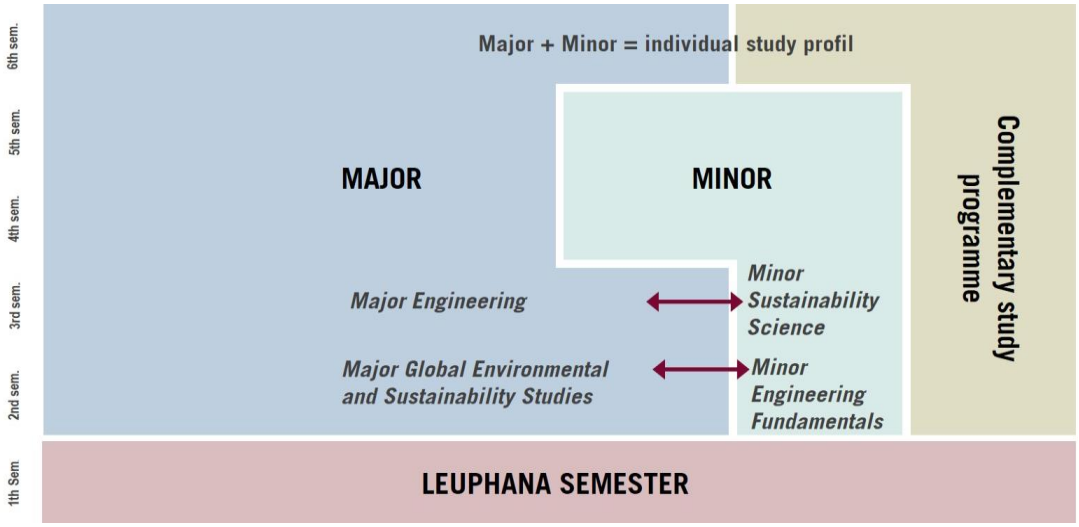

Fig. 3. *Leuphana Bachelor - Possibility of individualised profiling at the interface of technology and sustainability*

The M**ajor Engineering** provides a sound engineering and scientific knowledge as well as a deeper understanding of the controlling, optimising and controlling processes in digitised production and prepares students for the complex challenges of industry 4.0. Students of the **Major Global environmental and sustainability studies** acquire skills which will enable them to actively contribute sustainable development on a global level with an international perspective. The **Minor Sustainability Science** focuses on issues pertaining to the future of sustainable development. Students pursuing this minor will analyse the consequences of global change and develop sustainable solutions to real social problems that arise from unsustainable practices. The **Minor Engineering Fundamentals** provides an overview of the

most im portant technologies and technology-oriented processes in the manufacturing industry. To illustrate the close interlinking of engineering and sustainability, the content of the course “Electrical and Automation Engineering” is presented as an example, see **Table 3**. The course is one of six courses of the Minor Engineering Fundamentals (among others Mechanical Engineering, Manufacturing and Information and Communication Technologies).

Table 3. *Topics of the course “Electrical and Automation Engineering” with focus on sustainability, own data.*

Course Topics and technical contents	**Integration of technological innovations and industrial trends in the context of sustainability**
Electrical engineering basics (DC and AC technology)	Renewable energies, solar cells
Measurement and sensor technology	Smart Sensors, VR/AR and vision application for sustainability-oriented issues and responsible use of the resources
Control and actuator technology	E-Mobility

The course takes up on innovative trends, on the interaction of technical components in complex and interlinked systems as well as on a strong focus on transfer between theory and practice. Students get basic knowledge of selected systems, models, and parameters in the range of automation technology (**Table 3**) in the context of digitalization and sustainability. Students and lecturers willingness and motivation to “bring to life” the interdisciplinary discourse, and their readiness to deal with interdisciplinary problems as well as new scientific fields independently, leads to an profound preparation of students for their future career in interdisciplinary and diverse teams in the interface between sustainability and technology.

5 SUMMARY

The paper proves in a research-based manner that the topic of sustainability has so far been underrepresented in the engineering sciences, which is why evidence-based interdisciplinary implementation procedures such as those presented in **Sec. 4** are highly relevant. At SEFI 2022 conference the authors will discuss the experience of the curriculum implementation and future perspectives within the discipline of engineering education and research.

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