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Teaching Digital Sustainability in Higher Education from a Transdisciplinary Perspective

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Abstract: Sustainability is gaining importance in society, government, and the economy, particularly during today's rapidly changing environment, due to digitalization and digital transformation. Awareness, as well as systematic and critical thinking, are crucial to address the great societal challenges postulated within the SDGs, and thus should be reflected in contemporary education. Consequently, higher educational institutions face a high level of responsibility to prepare their students properly. Postgraduate programmes for professional training, in particular, have great potential, as the in-depth work experience of students can be leveraged to engage with them as co-leaders towards sustainable solutions in the digital age, from a transdisciplinary perspective. Thus, this paper introduces a teaching framework for digital sustainability in higher education under the light of transdisciplinarity. The framework and its inherent methods are discussed, followed by an exploratory analysis, covering the experiences of over 100 students over the course of two years in a postgraduate master's programme. We present the results of the students' learning and ideation process towards digital products/services to tackle challenges within the SDGs. In addition, we provide a critical reflection of prerequisites for teaching the framework, challenges experienced during teaching, and potential solutions, as well as ideas towards the future expansion of the framework.

Keywords: HEI; fourth mission; transdisciplinarity; digital sustainability; postgraduate studies

Citation: Lampoltshammer, T.J.; Albrecht, V.; Raith, C. Teaching Digital Sustainability in Higher Education from a Transdisciplinary Perspective. *Sustainability* **2021**, *13*, 12039. https://doi.org/10.3390/su132112039

Academic Editors: Maki Ikegami and Iain Patton

Received: 30 September 2021
Accepted: 27 October 2021
Published: 31 October 2021

1. Introduction

Sustainability is gaining importance in all areas of government, society, and the economy, and emerges in new fields of the inter- and trans-disciplinary discourse [1]. Preparing students for the increasing importance of this field and encouraging the critical discussion of issues of sustainability is a vital aspect of higher education and its discussion of sustainable development [2]. However, little research has been conducted on the transdisciplinary formalization and contextualization of this endeavour. Instead, research so far has focused on basic principles for teaching sustainability in higher education [3], the integration of (digital) sustainability in specific curricula [4], or sustainability as part of all the competencies imparted in a curriculum [5]. Additionally, with the rapid development of digital technologies, new challenges have emerged that require a critical reflection on digitalisation as a solution but also a potential threat to a sustainable life and economy [6].

While ecological sustainability and digital innovation seem to propose conflicting priorities, these developments are not mutually exclusive. On the contrary, societal, and economic innovation can be sustainable, and with some economic and political efforts [7], might even be enhanced by sustainability [8]. Put into a comprehensive framework through the sustainable development goals (SDGs), all aspects and manifestations of sustainability will determine all aspects of society, economy, and policy in the future even more so than today [9]. The ubiquity and width of addressing sustainability that the SDGs represent becomes apparent in the three pillars of sustainability [10]. These pillars contextualise

sustainability in the three areas of societal or sociotechnical sustainability (influencing a good and healthy life for all people), ecological sustainability (the 'classical' aspect of conserving nature and natural resources), and economic sustainability (combining healthy markets and responsible business practices with prosperity for everyone) [10].

Still, the awareness for the width of these developments does not yet fully exist, creating barriers in society and especially in business for thinking innovation and sustainability as one complex issue. While the initial developments, such as the evolution of not only corporate social responsibility (CSR) [11] but also corporate digital responsibility (CDR) [12], show a growing concern for the social and sustainability repercussions of commercial business practices, the necessity for more extensive changes in traditional economic practices is rapidly increasing. One important factor to foster this awareness is its introduction through different levels of education. To enable fast and sustainable changes, this especially includes higher and further education for senior staff in businesses and the public sector alike. This entanglement of sectors is important, as the underlying complex problems of today's society require knowledge across domains and disciplines [13]. Here, transdisciplinarity has an important role to play, as it "*[. . .] organizes processes that link scientific, theoretic, and abstract epistemics with the real-world-based experiential knowledge from outside academia*" [14] (p. 375) and thus *"[. . .] works out solutions through cooperation between actors and scientists*." [15] (p. 6). Therefore, transdisciplinarity represents *"[. . .] a synthesis of different modules, each with a clear orientation, and methodology [. . . to] be integrated into transformative discourses.*" [16] (p. 14). Before this background, inter-and trans-disciplinary courses can align different perspectives to build a common understanding of the concept of sustainability [17] in the context of digitalisation. Furthermore, early collaboration with industry partners can help to improve this inclusive character of planned curricula [18], especially when talking about postgraduate programmes. This engagement can be pushed even further, by explicitly offering international curricula [19] for cultural diversity.

In general, the previously described integration of sustainability aspects can either be pursued from a horizontal or vertical perspective. In the former, sustainability takes the role of a cross-cutting concern within an entire curriculum, while in the latter, it is positioned exclusively within a particular course or module [20,21]. While full integration of sustainability would be the ideal goal, one of the greatest challenges is often to simply start somewhere and build momentum. Thus, a low-barrier entry level with dedicated materials either as an add-on to an existing course or as a course of its own can be considered as a viable starting point [22]. It is then based on this starting point as a foundation that from a long-term perspective, the recommended horizontal integration [23] can be realized with an incremental participatory approach [24] of all involved key stakeholders.

One task that becomes more relevant for higher education institutions is to acquaint these stakeholders with the tension between digitalisation and sustainability. To integrate this transdisciplinary discourse in postgraduate education and impart the potential of sustainable and responsible innovation to students, we developed a framework for making the sustainable development goals part of a practice-oriented higher education curriculum. With this framework, we want to answer the question:

What does a framework look like that enables postgraduate students to understand the combination of digitalisation and sustainability applied in their own/organisational context?

To answer this question, in this paper, we propose a framework for introducing sustainable innovation in higher education classes. The goal of our teaching framework is to generate an understanding of combining digitalisation and sustainability in a practical environment. Our framework has been tested in a higher education institution with a focus on postgraduate part-time studies. To provide an insight into the implementation of this kind of curriculum, we address two specific research problems. First, we provide an explorative insight into the focus points that students developed in their practice-oriented examples, while they were being taught the sustainable development goals through the proposed framework. Second, we identify lessons learned during the implementation process, including barriers, problems, or open points, and suggest possible solutions. With

these lessons, future iterations of the framework will be able to be improved or scaled to other stakeholder groups, such as private businesses or graduate students.

The remainder of the paper is structured as follows: We first identify related work, contextualise the framework theoretically, and explain its development. To assess the value that the framework brings to a classroom in practice, we will present a sample of post-graduate part-time students to whom we taught in practice, and present content-focused and methodological results from the case from a transdisciplinary perspective. In our discussion, we evaluate these results through illuminating challenges to the framework and suggest extensions. We conclude with some recommendations for adapting the framework for further practical applications, and eventually different education levels.

2. Related Work

2.1. The Sustainable Development Goals

Decided in 2015 and put into action in 2016 by the United Nations, the 2030 Agenda of Sustainable Development marked the transition from the former and limited Millennium Development Goals [25] towards a new level of topic coverage and commitment. The 17 formulated Sustainable Development Goals (see Figure 1) comprise a wider range of grand societal challenges (from a social, ecological, and economical point of view), making them applicable beyond specific (e.g., only developing) countries.

Figure 1. All 17 defined Sustainable Development Goals, adapted from [26].

The SDGs are defined in a way that they are not silos but encourage synergies between one or several goals. In addition, aspects such as partnership, collaboration, and policy, in general, are pushing towards an accelerating base for achieving the desired goals. While not being enforced as a law, regulation, or directive, the SDGs have become a worldwide anchor point and common frame for strategic action plans and decisions to address the grand societal challenges [27]. It is this common set of goals, values, and also language that need to be communicated, calling upon higher educational institutions (HEI) to act according to their responsibilities and to transfer these competencies into their curricula to ultimately implement this sustainable seed into their target audience [28].

2.2. Teaching Sustainability in Higher Educational Settings

A major aspect of sustainability teaching at higher educational institutions is the educational training of teachers, supervisors, and lecturers. Badea et al. [29], for example, investigated the importance of the involved staff and sustainability activities at universities and found these to be crucial for the development of the students' own behaviours considering sustainability. In the context of German universities, Hoinle et al. [30] discuss in their work an analysis of interdisciplinary sustainability certification programmes, covering opportunities and hurdles of teaching sustainability in the context of regional transitions. Connecting to the regional aspect, Gómez-Ruiz et al. [31] developed a serious play-based approach for teacher education in an outdoor setting concerning sustainability for territorial and heritage realities. Staying within the topics of teacher education and cultural heritage, Molina-Torres [32] reports about primary degree students and their training in the domain of protection and sustainability of community museums. Finally, Expósito and Sánchez [33] investigated and successfully demonstrated how to train university teachers towards the adoption of sustainability via the TMTAS model, which led to the successful transformation of syllabi, including objectives and competencies. So, we see that regardless of the application domain, the training of staff is important and is required as a solid foundation for the transformational process, which the students are going through. This also includes self-reflection and lessons learned from the teaching approaches, so a continuous development and improvement cycle for frameworks and curricula can be realized.

Continuing in the field of sustainable student behaviours, Braßler and Sprengler [34] introduced in their study an interdisciplinary approach towards higher education for sustainable development (HESD) in the context of a German university. They focussed on the observing of arising attitudes and behaviour of students during their journey of acquiring knowledge in the field of sustainability. Their approach combines lectures of domain experts, accompanied by a set of supporting tutorials. It is especially the domain experts that can help to trigger the shift in thinking towards real-world sustainability problem-solving. The importance of critical reflection for students is also stressed by Berasategi et al. [35], who demonstrated the use of case-study-based approaches and how they can foster joint, interdisciplinary work and skill development. Mets et al. [36] argue in a similar direction, concerning the importance of transdisciplinarity on the example of entrepreneurship-focused education in sustainability contexts. This is also further endorsed by Hermann and Bossle [37], stressing the importance of external collaboration, and thus being able to address complex community and societal problems. Derler et al. [38] take the concept of critical thinking, collaboration, and external input for the identification of real-world problems one step further. They argue that the teaching staff, while playing an important role considering the provision of the overall organisational setup, step into the background and act as designers of the learning space. In consequence, students accelerate to a pivotal position on project-based case studies, transforming from knowledge consumers to knowledge creators. This learning process around a focal point (problem) enables cooperative learning between the students and their peers, while at the same time, they grow as a team and take over ownership and communication of their solutions and results.

In summary, we see that the set of problem-based learning [39], case-study-based approaches [40], as well as service learning [41], as examples of active education methods [42], are amongst the most used and established methodological sets within teaching sustainability in higher education [43]. In order to fully grasp the potential of these methods for solving complex societal challenges, collaboration becomes crucial. That being said, this collaboration needs to go beyond established disciplines or organisational boundaries and embrace inter- and trans-disciplinarity. By doing so, codesign and cocreation targeted at real-world problems become possible and lay the solid foundation for the required societal impact [44]. This desired impact can be understood as a call for the fourth mission for higher educational institutions [45]. To provide the necessary means for sustainable knowledge transfer, the context of the framed problem is important [46]. Thus, from the

very beginning, the inclusion of practitioners at eye-level should become an integral part of all activities and should be considered when suitable [47].

Considering these aspects within the context of our research question, we have designed our framework accordingly. As the underlying method for the student activities, we use a mix of problem-based learning and case studies. The high heterogeneity of the student groups, with different industrial and educational backgrounds, in combination with tutoring and guidance from supervisors/lecturers, provide a vivid and active environment for interdisciplinary exchange. Furthermore, as all students are professionals and work in various sectors in differently-sized companies and organisations, we can— following a transdisciplinary approach—include this expertise from the very beginning, anchoring the students' work on real-world challenges in the context of using digitalisation to overcome sustainability issues. The international aspect introduced by the students from Austria and Germany positively adds to this setup. Overall, the suggested framework provides a low-barrier entry into teaching digital sustainability to establish an initial building block within existing curricula towards an—on the mid- and long-term—potential horizontal integration of sustainability. Finally, the reflexive discussion and presentation of lessons learned from the case study (piloting) of the developed framework will support the lecturers/supervisors in their endeavour to teach sustainability in the context of digitalisation and digital transformation.

3. Teaching Framework

The designed framework in its entirety can be seen in Figure 2. As prior inquiries among the students have shown, most of them do not know about the details concerning the sustainable development goals or only have limited experience with the topic of sustainability, mostly in ecological production and resource management. Thus, the students are provided with an introduction to the SDGs, their background, and their diverse target domains and areas (step one). Additionally, the students are introduced to the role of Information and Communication Technology (ICT), as well as digitalization in the context of SDGs.

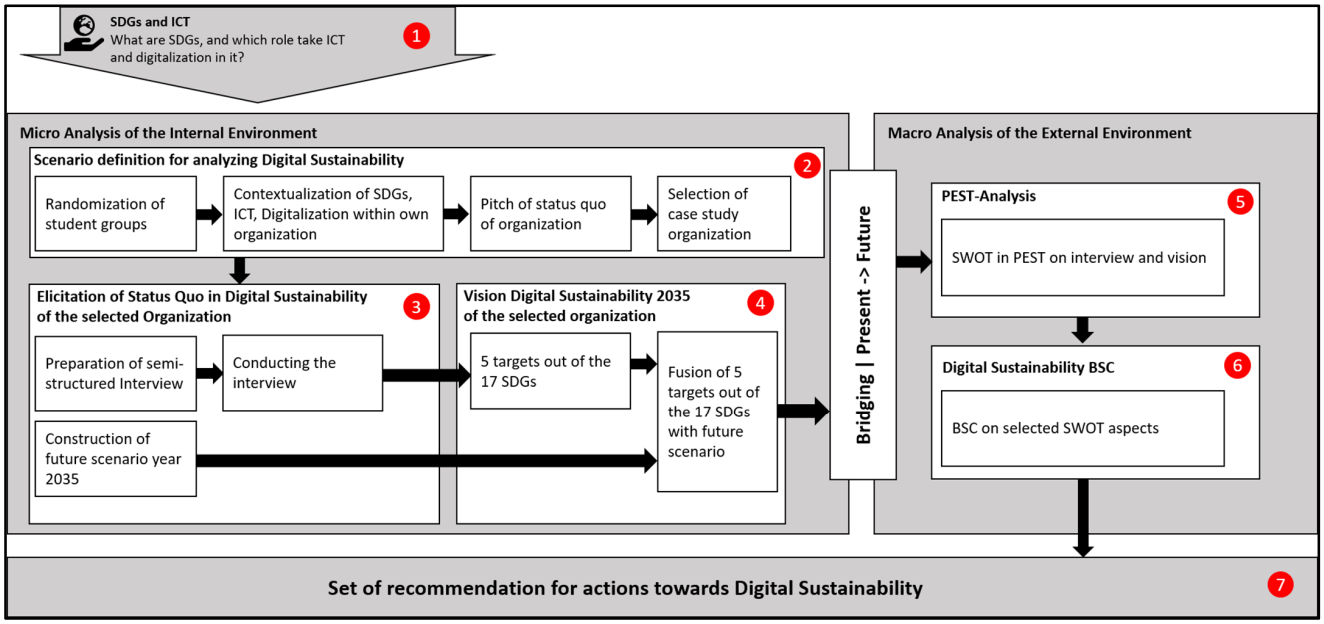

Figure 2. Workflow within the Digital Sustainability teaching framework.

In the next phase (step two), students define the scope of their scenario which they are going to investigate and analyse during the course and assess its potentials for digital sustainability-based solutions. As all students are studying part-time, it is important to

connect the respective scenario to their own professional experience and environment, as this improves comprehension of the tasks and eases the task of working on an unknown topic. To encourage students to cross-cultural barriers (in this case, differences between sectors or types of business environments, also in different countries) and improve knowledge spillover between the students, randomized groups of four are formed [48]. This also helps to spread out the heterogenous backgrounds of the students, as they tend to remain in closed study groups within the cohort, mostly within a particular discipline or working background, e.g., consultants with consultants, or security specialists with security specialists. After the formation of the groups has been completed, the students are introduced to deeper the concepts of digitalization and SDGs to tie in with the initial introduction in step one. This time, each student assesses potential connection points and application domains within their own company or organization. Guiding questions for the students comprise among others: *"What are domains or areas the SDGs address, which are also relevant for your company/organisation at the moment?"*, *"What are new areas/domains your company/organisation is planning to focus on in the future and where are touching points to the SDGs?"*, *"Is your company/organisation already confronted with challenges included in the SDGs or will it be confronted in the near future?"*, *"Is there already a digitalisation or digital transformation agenda in place, which has touching points to the general areas of the discussed SDGs?"*.

After the students have processed the second input round and completed their notes and points of reference, their next task is to prepare an individual pitch (with a duration of 2 $\frac{1}{2}$ min) of why their company or organisation has the most potential to be discussed during the course by the student's respective group. Guiding questions along this task include: *"Please describe our company/organisation, what is its focus, how does it generate revenue?"*, *"What are the core products/services of your company/organisation?"*, *"Is your company/organisation a forerunner in terms of digitalisation and digital transformation, or is it driven by it and lacking behind?"*, *"What is the position of your company/organisation on the market (leader, niche)?"*, *"What are the main touching points towards the topics/domains addressed by the SDGs?"*. Each student within each group is then pitching his/her company or organisation to his/her fellow group members. The group then jointly decides which company or organisation to analyse during the course.

Once the company or organization has been selected, the students enter the next phase (step three). Here, the groups split up. While the students whose companies or organisations were selected ("pitchers") are leaving their groups, the rest of the members in each group prepare a set of guiding questions to interview their respective "pitcher", to gain a better and deeper understanding of the company or organisation, as well as touching on points and potentials concerning the SDGs. This builds on the idea that a combination of external knowledge acquisition and internal knowledge transfer improves the innovation capacity of businesses [49]. Meanwhile, the "pitchers" are constructing a future vision of the year 2035, facilitated by the lecturer. The idea behind this methodological step is to define a future environment (market) scenario, in which the yet-to-be-developed digital products/—addressing SDGs—are going to reside. To support the building process, the scenario is structured via four different categories, i.e., core topics (e.g., political, economic, societal, technological), consequences and challenges, drivers, and hurdles. As all "pitchers" are involved in the process, they are automatically introducing the interests of their companies or organisations into the future scenario. Thus, we derive a framing picture with synergies, as well as with the potential for conflicts, just as you would expect from a real environment (market). The date of 2035 is chosen as it is about 15 years far enough into the future to be useful for "fantasies and ideas", while at the same time being close enough that students are able to connect it to the present situation and environment their companies or organisations reside in. Additionally, before starting with the future scenario-building process, the students are presented with sample cases to demonstrate what significant jumps companies and markets can make. These sample cases include, e.g., Apple introducing the iPhone and creating the concept of a smartphone, Facebook creating the concept of online social network platforms, etc., or how political environments

can rapidly and disruptively change, e.g., the political shift in the US from the Trump to the Biden administration, or the current Brexit situation. After the future scenario has been completed, the "pitchers" return with the jointly developed scenario back to their respective groups, to be interviewed by them.

After the completion of the interviews, the students within each group design the vision and product/service ideas, in association with the results of the interview, as well as the future scenario 2035 (step four). To form this step in a more concrete way, the students are to select five targets out of the 17 SDGs for their digital services/products. These targets can either be sourced from one SDG or distributed over several SDGs. After the selection is complete, the students work on their actual ideas for digital services/products. In this stage, an initial idea is sufficient, comprising about one or two paragraphs per idea.

After the ideas are formulated and documented, the students proceed with identifying potential drivers and hurdles of their developed ideas (step five). In order to do this, the students apply the SWOT (Strength-Weaknesses-Opportunities-Threats) method [50]. The reason for the selection of this particular method is due to its ease of application and—at least during its initial steps—low complexity. Yet, to properly frame the SWOT analysis into the existing environment that the students have constructed (vision of 2035), the SWOT analysis is combined with a PEST analysis (Political-Economical-Societal-Technological) [51]. There exist several modifications of PEST such as PESTEL [52], which also include legal and ecological impacts. This variant has not been adopted for two reasons. First, the lacking legal background of the students, and second, as the SDGs already heavily include ecological inputs, an explicit integration into the assessment framework would be redundant at this point and therefore would not lead to new, additional insights. Overall, the students perform a complete SWOT analysis for each of the four dimensions of the PEST analysis.

Succeeding this in-depth analysis, the students continue in step six with the construction of a balanced scorecard [53] within the domain of digital sustainability. Here, students create concrete, tangible, and measurable outcomes per chosen category. The students reduce the selection towards four different perspectives, i.e., S, W, O, T, and construct for each of them a set of (i) general target directions, (ii) concrete and measurable goals, (iii) way measuring measure the success rate concerning the chosen goal, and (iv) a suggestion for a concrete action to undertake in this direction.

In the last phase of the framework (step seven), the students reflect on their overall results and choose the digital product/service with the best overall results. For this selected idea, they prepare a presentation for their peers including all steps from the original starting point (i.e., the status quo at the company or organization), to throughout the entire ideation and refinement chain, until the set of concrete targets, goals, measures, and actions has been presented.

4. Case Study

4.1. Description of the Student Cohort

In order to validate our teaching framework and to further improve it, the framework was established as a dedicated course named "Digital Sustainability" in two postgraduate programmes, i.e., Professional MSc in Management and IT (MIT), as well as the Digital Corporate Governance (DCG) MBA. Both of these programmes are hosted at the University for Continuing Education Krems (Danube University Krems) in Austria. This public university specialises in enhancing the qualifications of working professionals. Thus, it currently only offers postgraduate programmes (Note: the current definition of postgraduate studies in the context of Austria means that students can either receive professional education at a university on basis of a previous academic degree or by featuring a professional education with a substantial amount of work experience. That being said, due to the current changes in the Federal Act on the Organisation of Universities and their Studies in Austria, students that would like to enter a postgraduate programme must in the future either have already successfully completed an academic degree or enter a Bachelor Professional or Bachelor of Continuing Education programme, before they can move up to a postgraduate master's

programme), besides its Ph.D. programmes. At the moment, there are about 8000 students enrolled, with about 26,500 alumni having successfully completed their studies.

The course was offered over a period of two years, with a total amount of 117 students participating. The majority of students were enrolled in the MIT programme, with 12% of the students being enrolled in the MBA programme. About two-thirds of the students were Austrians and about one-third were German students. The median age of the students was 36 years, with a median work experience of 16 years. Most of the students were males, with only about 10% of the students being female. Considering previous education, 55% of the students had completed professional training, while 35% had the completion of A levels as their highest level of education. Only 10% of the students had finished a university degree previously. The full details about the student cohort can be seen in Table 1.

Table 1. Statistical summary overview of all students participating in the case study.

		Year 1	Year 2	Total	% of Total
No. of students per class		75	42	**117**	**100%**
Program	DCG => MBA programme	10	4	**14**	12%
	MIT => Master's programme (MSc)	65	38	**103**	88%
Nationality	German	23	20	**43**	37%
	Austrian	52	22	**74**	63%
Gender	Male	68	35	**103**	88%
	Female	7	7	**14**	12%
Age (in years)	24–30	19	13	**32**	27%
	31–36	14	13	**27**	23%
	37–42	15	9	**24**	21%
	43–48	21	6	**27**	23%
	>48	6	1	**7**	6%
Highest completed level of pre-education	Apprenticeship	37	24	**61**	52%
	Professional school	3	0	**3**	3%
	A-levels	27	13	**40**	34%
	University (bachelor's and/or master's degree)	8	5	**13**	11%
Years of professional experience	<=5	3	5	**8**	7%
	6–10 J	11	9	**20**	17%
	11–15J	22	8	**30**	26%
	16–20J	14	10	**24**	21%
	21–25 J	14	8	**22**	19%
	26–30 J	7	2	**9**	8%
	>30 J	4	0	**4**	3%
Years of leadership/management experience	None	8	9	**17**	15%
	<2	0	1	**1**	1%
	2–3	9	11	**20**	17%
	4–5	12	3	**15**	13%
	6–7	2	5	**7**	6%
	>7	44	13	**57**	49%
Hierarchy level	Employee	41	25	**66**	56%
	Lower management/team lead	11	7	**18**	15%
	Middle management	12	9	**21**	18%
	Self-employed/chief executive	7	1	**8**	7%
	Top management/C level	4	0	**4**	3%
The economic sector of employing company or organization	Secondary	37	28	**65**	56%
	Tertiary	38	14	**52**	44%
ISIC classification of employer's economic activity	10. Information and communication	16	2	**18**	15%
	11. Financial and insurance activities	2	1	**3**	3%
	13. Professional, scientific and technical activities	7	7	**14**	12%
	14. Administrative and support service activities	2	0	**2**	2%
	15. Public administration and defence; compulsory social security	3	2	**5**	4%
	16. Education	2	0	**2**	2%
	17. Human health and social work activities	2	0	**2**	2%
	3. Manufacturing	37	28	**65**	56%
	7. Wholesale and retail trade; repair of motor vehicles and motorcycles	2	1	**3**	3%
	8. Transportation and storage	2	1	**3**	3%

4.2. Explorative Results of the Student Groups

To be able to evaluate to what extent the students were able to address the SDGs via the framework, the authors evaluated the main SDG, the pillar (ecological, economic, or sociotechnical) of sustainability, and the topical focus points of the student examples. The SDGs addressed by the student groups have either been explicitly stated in the resulting material or have been determined by the authors evaluating the study group results, in edge cases, where multiple associations would have been possible. The distribution of SDGs selected by the student groups can be found in Figure 3.

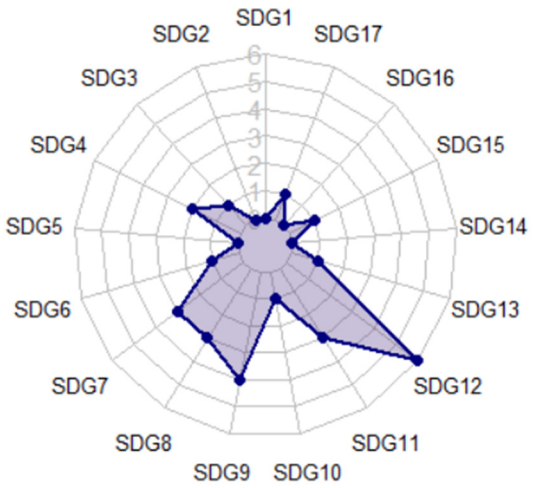

Figure 3. Distribution of SDGs in student solutions.

Since our main emphasis is to assess how the proposed framework influences the students' confrontation with the SDGs, in the following section we present the outcomes of the working groups in relation to the SDGs that have been addressed in the course.

The framework presented in this paper has the goal of including the SDGs in higher and especially in continuing education. To evaluate to what extent the results of the case in which we tested the framework show the fulfilment of this objective, in this section, we present a closer look at the SDGs that have been analysed and addressed by the students. A first look at Figure 3 shows that teaching the framework succeeded in addressing a broad inclusion of varying SDGs. A total of 12 out of 17 SDGs have been addressed and the respective topics that deal with them will be shortly explained. As can be observed from Figure 3, most cases understand sustainability in a more economic sense, i.e., efficiency, and consequently address the SDGs 9 and 12. In the following, we present the context in which the SDGs have been addressed, looking at them in numerical order (according to the list of the SDGs 1-17), see also Figure 4.

The first goal that has been addressed by one group is SDG 3, "Good Health and Well-being". The innovation that has been developed by the students concerns the improvement of air quality in production facilities and public areas and suggests the development of an advanced air purification filter to achieve this goal.

For SDG 4 "Quality Education" the developed proposals address mainly the education of employees and trainees in the case of companies and organisations. The two solutions proposed include training in e-commerce via an education platform and the proposal to develop further career opportunities through training and education. The focus here is mainly on the economic understanding of sustainability, intending to avoid brain drain and reduce staff turnovers in the respective businesses.

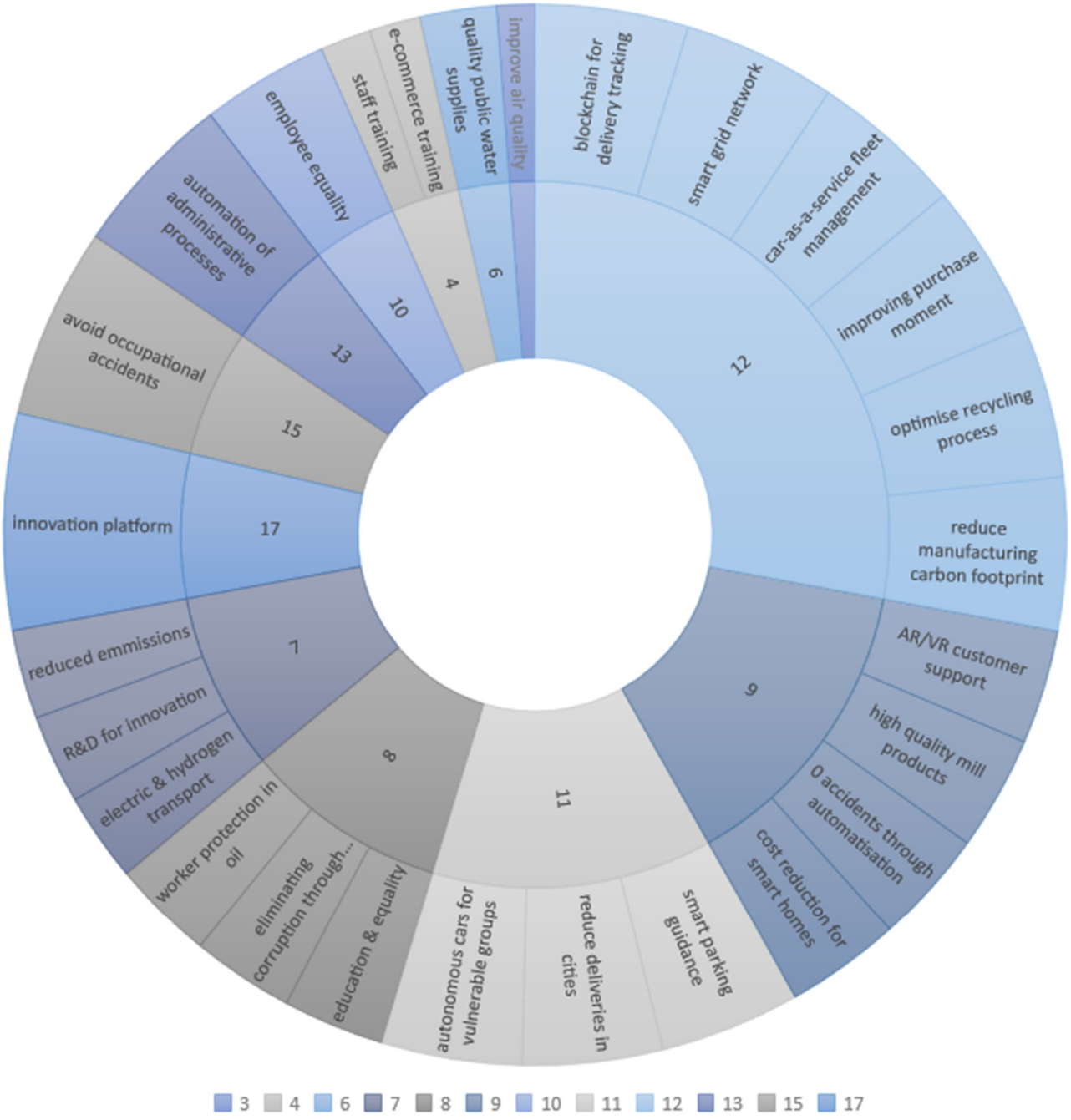

Figure 4. Overview of addressed topics per SDG.

SDG 6 "Clean Water and Sanitation" was addressed by only one group, concerning a case from the public sector. To prevent the entry of lower-quality water suppliers into the public sector (through marketing, high-quality water and public monopoly), efforts should be made to guarantee that the local water supply remains at 100% over the next 50 years. For that, marketing, water quality, and infrastructure should be secured by the relevant public authority.

A higher number of results related to SDG 7 "Affordable and Clean Energy". Two of the solutions presented by the students explicitly focused on the objective of reducing CO2 emissions: One group proposed cost and emission reduction through smart and connected facility management, another group focused especially on the reduction of CO2 emissions through electric and hydrogen drive systems, while also proposing more

extensive marketing and advertising. A third group suggested an improvement in research and development to develop a fully independent energy supply and recovery system.

SDG 8 "Decent Work and Economic Growth" was also addressed by three of the student groups. The proposed measures included compliance to legislative requirements of worker protection and internal audits in mineral oil production, the automatization of processes to eliminate corruption, and the support of gender equality, as well as decent working conditions in international production sites.

The SDG which was addressed by the second-highest number of cases was SDG 9 "Industry, Innovation and Infrastructure". This goal was addressed by four student groups which focused on examples from very different industries and in a wide variety of innovations. One suggestion concerned the reduction of costs for customers in metal industries through the optimisation of and waste reduction in the production process of smart and automated home devices. Another group presented a plan to eliminate accidents by using autonomous vehicles. The other two groups focused more on the customers by proposing better quality management in food mill productions and the introduction of AR/VR support for customers of a 3D printing business to achieve market leadership.

SDG 10 "Reduced inequality" was the main goal addressed by one student group who wanted to improve training, equality, and processes for employees in the automotive sector to further equal wages, transparent negotiations, and equal access to training programs.

Three student groups addressed SDG 11 "Sustainable Cities and Communities". The proposed solutions in this area range from research and technological development for more accessible, autonomous, and sustainable cars, to reducing deliveries in cities by combining the transportation of passengers and goods, to smart city parking guidance systems with smart contracts (blockchain) for more effective use of parking spaces.

The highest interest among the students concerned SDG 12 "Responsible Consumption and Production". This supports the focus on more economic SDGs. However, most of the presented solutions also addressed measures to combat climate change or reduce the businesses' carbon footprint, respectively. Altogether, six ideas were developed that addressed SDG 12. The first concerned the reduction of the carbon footprint in manufacturing, as well as the responsible and sustainable use of natural and personnel resources. Another group with a similar goal proposed the development of sustainable energy through a smart grid network. The optimisation of recycling and waste management, according to the students, could be achieved through employee education and additional infrastructure and would lead to additional revenue for the automotive company. Other solutions that were proposed in the context of this SDG concerned more efficiency in fleet management for a car-as-a-service provider (including a higher fluctuation and the investment into electric cars), in the timing of a purchase from a manufacturing supplier, and 100% traceability in deliveries through the use of blockchain technology.

Only one of the student groups addressed SDG 13 "Climate Action" as the main goal for their solution. This group had the additional differentiator of being only one of two groups who choose public administration as their use case. To initiate climate action in their regional administration, the students suggested the improvement and transparency of administrative processes, as well as an increasing number of AI or AI-supported decisions.

SDG 15 "Life on Land" was also addressed by only one group. They set the goal of avoiding or minimising heavy physical work and the resulting occupational risks. Through the use of technologies such as drones and political regulation, occupational accidents in the packaging industry could be reduced by 75%.

One group set their priority around SDG 17 "Partnerships to achieve the goal". To maximise profits, attract customers, and reduce development costs, one group suggests that an automotive company develops an innovation platform and uses framework contracts to find synergies.

4.3. Explorative Cluster Analysis of Student Groups

In order to further investigate the structure of the student groups, including demographic information in comparison with their project results, we conducted a hierarchical cluster analysis [54]. For the sake of this analysis, we formed a dataset, describing each of the 27 groups via the following features: their specific sector, their ISIC (International Standard Industrial Classification Economic Activities Rev.4) classification, SDG classification (EFS) [55], their age, their educational level (0-professional training; 1-A-levels), their leadership experience in years, and their overall work experience in years (Note: the demographic information is related to the student representing the company/organisation and thus the respective case-study for each group. This choice has been made as we have observed during the course that the representative served most of the time as a kind of gatekeeper for new ideas into the existing company/organisational space). For performing the actual analysis, the statistics software R [56] was used. Figure 5 shows the resulting dendrogram and the clusters contained within.

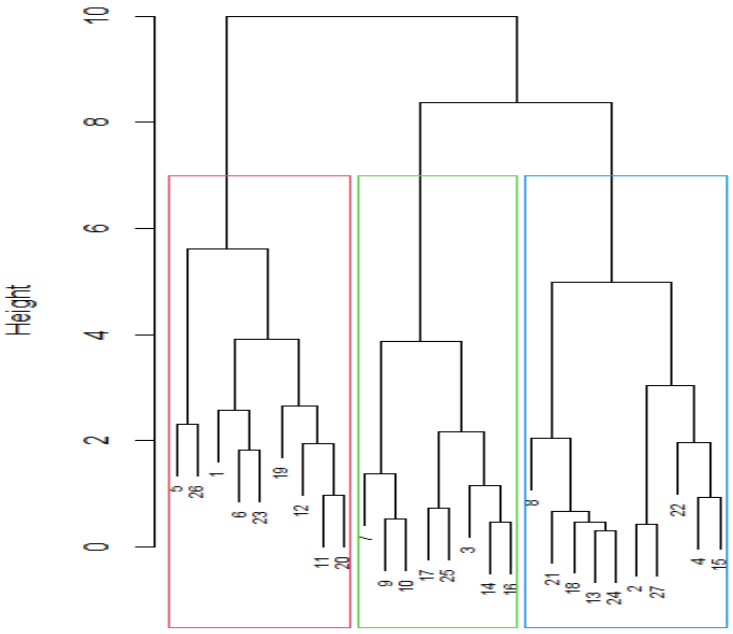

Figure 5. Dendrogram of the three identified clusters (from left to right—cl1, cl2, cl3), based on the "ward.D2" method, where the numbers represent the respective student group ID.

In order to assess the clustering structure of the data at hand, we calculated the agglomerative coefficient (AC) [57], as provided by the *AGNES* package [58]. This coefficient ranges from 0–1, representing the mean of the normalized lengths concerning the creation of the respective clusters. The closer the coefficient is to 1, the better is the underlying structure [59]. We tested the available clustering methods included in the package *cluster*, i.e., 'single, average, complete, and ward'. The best results for the provided dataset were achieved via 'ward, resulting in an AC of 0.84. Concerning the selection of the optimal number of clusters, we used the *NbClust* package [60]. This package includes a set of 30 indices for testing for the optimal number of clusters. The overall result is reached by a majority vote of all algorithms towards a particular number. In this case, the number of clusters was three. Table 2 shows the respective details for each group's attributes associated with the respective cluster

Table 2. Attribute details for each student group and their assigned cluster.

GROUP ID	SECTOR	ISIC	EFS	AGE	EDU LVL	EXP OVERALL	EXP LEAD	CLUSTER
1	3	7	2	43	0	22	16	1
5	3	15	3	39	1	8	7	1
6	3	8	1	30	0	15	9	1
11	3	11	1	43	1	13	7	1
12	3	10	1	30	1	8	0	1
19	3	10	1	41	1	25	0	1
20	3	8	1	39	1	11	0	1
23	3	13	1	39	0	18	0	1
26	3	15	3	31	0	11	11	1
2	2	3	1	30	0	11	5	2
4	2	3	2	30	0	9	7	2
8	2	3	2	30	1	10	7	2
13	2	3	1	26	1	6	0	2
15	2	3	2	34	0	14	5	2
18	2	3	1	28	1	9	3	2
21	2	3	1	24	1	5	3	2
22	2	3	3	28	0	7	3	2
24	2	3	1	26	1	8	5	2
27	2	3	1	27	0	11	3	2
3	2	3	1	37	0	17	5	3
7	2	3	1	36	1	18	7	3
9	2	3	1	44	1	24	7	3
10	2	3	1	42	1	21	0	3
14	2	3	1	43	0	21	7	3
16	2	3	1	44	0	18	13	3
17	2	3	1	45	0	30	13	3
25	2	3	1	45	0	25	3	3

When inspecting cluster 3, we can see that we have a homogenous cluster within the secondary sector, focussing solely on manufacturing. While the difference in the educational level compared to the other two clusters is neglectable, the cluster features the highest levels with regards to the average age of 42 years, average work experience of 22 years, and average years of leading experience of 7 years. If we combine this observation with a logical grouping of the SDGs addressed by each of the groups, something interesting is unveiled. For the purpose of grouping the SDGs, we followed the work of [55], partitioning the SDGs into elements of ecological economics (EFS):

1. Efficient allocation: SDGs 7–9; SDGs 11–12;
2. Fair distribution: SDGs 1–5; SDG 10; SDGs 16–17;
3. Sustainable scale: SDG 6; SDGs 13–15

When we now revisit cluster three and compare it with cluster one, and we can clearly see that with a reduction of age but also work and leading experience, we obtain a higher variety in terms of SDG foci, moving away from pure efficient allocation. Then, again, and this is particularly interesting, the same goes for the "youngest" cluster (2), where most students are still in the secondary sector and manufacturing, but we also see these groups opening up to dimensions beyond efficiency. While these insights are explorative results, one possible interpretation might be that—especially in production environments—the "old guard", which was trained in optimisation, is still predominant, but younger generations—who have changed perspectives and educational training—are opening up innovation spaces in classical and more conservative sectors.

5. Discussion

During the implementation of the curriculum, we observed some important aspects that should be taken into consideration when applying the presented framework and when it comes to extension and future work. We formulated the arising issues in the form of

postulated questions, which serve then as a basis for discussion. The questions are divided into two main parts: (i) aspects of the target group of postgraduate students, as well as challenges and solutions concerning the teaching of the framework; (ii) potential extensions to the framework itself.

5.1. Target Group and Challenges to the Framework

1. Are there specific hurdles in transferring the presented framework from the postgraduate sector towards classical bachelor's programmes?

There do exist several points that should be carefully taken into consideration when moving the framework out of the postgraduate and into the classical bachelor programs. One of these points corresponds to the professional background of the students. All students in this study have a professional background of several years. This sets them apart from their younger colleagues, not only in terms of age but also in terms of in-depth knowledge of, e.g., industry domains and common challenges. On the other hand, postgraduate students that directly enter the academic program with a prior academic degree (e.g., in the case of MBAs, etc.), often show a lack of knowledge and/or experience when it comes to scientific methods. Thus, lectures/supervisors need to take this into account and support the students by either providing the required background information concerning the relevant industry sectors and/or support students on the selection and application process of the necessary scientific methods for working on the presented cases.

The second important point comes in form of the required in-depth knowledge of the case company or organization. While in the presented study, all cases had companies/organization representatives in form of one of the students, this can be a challenge in Bachelor programs, especially considering full-time study programs, where the students are more likely to not have this in-depth knowledge of a company/organization. Hence, this requires that the lecturers/supervisors carefully prepare and select cases that the students can work on. This includes the provision of starting materials, as well as the definition of concrete boundaries, in the case of large companies or organizations, so the students do not get lost during the analysis phase. Here, the lecturers/supervisors have to make a design choice. Either all students are analysing the same company or organization, which can be useful later for cross-comparison, or they have to present different cases to each group. In the latter case, this requires a careful inspection of the cases, so they are equal in terms of size and complexity, which ultimately leads to a higher number of resources required from the lecturers/supervisors.

2. Are there any constraints considering prerequisites to execute the proposed framework?

The entry barrier considering the presented framework is rather low. However, depending on the students' backgrounds and educational level, larger efforts might need to be undertaken in the preparation phase (see discussion in 1.). Besides this, another important point comes in form of time constraints. Depending on the overall available time for the course and thus for the students to execute their assigned tasks, it can be quite stressful. It is important to understand that it is virtually impossible to expect fully-fledged solutions within a 1-day workshop. In the case of shorter timespans, it should rather be seen as a form of familiarization with the challenges associated with the SDGs, and a first ideation phase towards a set of ideas and concepts, which can then consecutively serve as the basis for further elaboration, e.g., in form of essays, theses, or student projects in general.

In addition, lecturers/supervisors need to carefully decide on the selection and/or replacement of methods within the presented framework. The current selection has been intentionally designed with students in mind that might not have in-depth experience with complex methods. Additionally, the more complex a set of methods becomes, the more time and resources are required to correctly execute all necessary steps. That being said, the current set of steps and methods should not be mistaken for a lack of rigor due to their accessibility. Furthermore, lecturers/supervisors should try to incorporate synergies to other courses and the methods employed there. This further reduces the entry hurdle,

reassures students concerning their capabilities, and at the same time provides additional training concerning the application of already-learned methods in different scenarios.

3. What challenges arose during the individual steps of the framework and how can they potentially be mitigated?

Naturally, during the course of executing the framework, challenges arose which were not foreseen during the design phase. In the following, for each step of the framework, challenges are described, and mitigation methods are presented. An overall overview can be seen in Table 3.

Table 3. Overview of challenges and mitigating solutions for teaching the framework.

Step #	Content of Step	Problem Challenge/Open Point	Methods for Mitigation
1	Introduction of SDGs, ICT, and digitalization	the challenge of sustainability awareness	Involve senior students in peer exchange and mutual learning
2	Scenario definition	the challenge of scenario definition	• use of an extended set of guiding questions • additional cases of companies or organisations of higher maturity in related sectors
3	Elicitation of status quo	• the challenge of preparing the interview • the challenge of imagining the future	• fallback to set of standardised interview questions • work with real-world cases that have disrupted their respective business sector
4	Vision creation	• the challenge of picking SDG targets • the challenge of seeing the larger picture	• instead of targets, open up the alternative to focus on the general theme of each SDG • foresee the integration of key technologies for each group in the future scenario as an anchoring point
5	PEST analysis	the challenge of going beyond financial aspects	• either exclude financial aspects as valid solutions • or foresee the financial dimension as default and demand at least one or two additional ones
6	Digital Sustainability BSC	the challenge of measuring what matters	• use familiar KPIs as a basis for metrics and measurements
7	Formulations of recommendations	the challenge of pitching the results	• use guided and standardised templates • student peer review and scoring for quality assurance

Step 1—the challenge of sustainability awareness: We experienced that although the students were aware of sustainability as a concept, they were not always aware of the SDGs themselves. Additionally, a lot of companies and organisations have no concrete action plan concerning sustainability, while others are embracing it as a cornerstone within their mission. Naturally, this creates tension between the companies and organisations that are more mature in this regard and companies or organisations that are just starting. This also reflects on challenges concerning the introduction, so as not to bore one group or overwhelm the other one. A potential solution to this conundrum can be to invite more advanced groups to share some experiences during the introduction phase of the SDGs and sustainability as a mission concept. By doing so, the other students receive, in their own language, information that can be helpful for them, while at the same time, encouraging the other students and giving them an important role within the course.

Step 2—the challenge of scenario definition: This challenge is the logical consequence of the previously-presented challenge. Due to the different maturity levels, students might experience difficulties in connecting the information presented to their specific company or organisation. That being said, this goes two ways: on the one hand, students with high maturity levels in their companies or organisations might struggle to find new and innovative ideas, as from their perspective "everything already exists". On the other

hand, students from companies or organisations with a low maturity level might not see any connecting points at all. A potential solution to this challenge is the preparation of guiding questions for the students. Yet, this would also lead to early streamlining, which could prove counterproductive. Another aspect could be the introduction of companies or organisations that already have a higher maturity level. These could be introduced by reports of students working in such environments and reporting about the internal development phases, hurdles, success stories, etc. That being said, this would either require additional, outside students, e.g., in higher semesters. If students from the very same group are invited to present, this puts an additional preparational burden on them that needs to be taken into consideration in terms of time, grading, ECTS, and so on.

Step 3a—the challenge of preparing the interview: The method of interviews was selected, as students are required to think about critical questions in advance, and also need to balance the direction from which they approach the interviewee. All students in this study had already undertaken methods courses, covering interviews and qualitative analysis. That being said, if this prerequisite is not met, a set of base questions should be provided to guide the students. While this introduces a certain standard, overall coverage to groups conducting interviews, it might also limit the perspective and information that can be acquired if students stick too much to the provided questions and do not go beyond them.

Step 3b—the challenge of imagining the future: One central part of the framework is presented by the construction of a future scenario; the students have to integrate their concepts and associated productions and services. In order to provide them the required flexibility and to leave enough space for creativity, the time dimension is set more than a decade into the future. However, we have seen that the students are often blocked and captured by their daily business routine within their professional environment, and thus had found it hard to project into the future, leaving behind current constraints. To guide them within this process, we provided them with some real-world examples that made such big, visionary jumps, e.g., the introduction of the iPhone as the first smartphone, YouTube, Facebook, etc., and how they were initially conceived and developed over time.

Step 4a—the challenge of picking SDG targets: Facing the task of selecting targets out of the SDGs, the students reported difficulties for some of the SDGs and the associated targets regarding transferring them into their context, i.e., industrialised countries in Central Europe. While some of the students found a way to transport their ideas into the context of developing countries, most students fell back onto the general domain of the SDG and abstracted the targets accordingly.

Step 4b—the challenge of seeing the larger picture: Of course, developing the product and service ideas is only half of the story. In order to increase the realism of the setup, the students had to develop a future scenario, into which they have to embed their ideas. This is particularly important, as they also have to take care of positions and trajectories of other student groups. In order to support them here and to avoid cases of the ideas not considering the future scenario at all, each student group was required to explicitly refer to anchor points within the future scenario. This was accomplished by, e.g., certain key technologies that are highly relevant to the group which have been introduced during the development phase of the future scenario. As the other groups have also contributed to drivers and barriers of these technologies, this automatically provides the required minimum embedding.

Step 5—the challenge of going beyond financial aspects: During the SWOT analysis for each of the PEST dimensions, we discovered that the students tightly followed the exemplary suggestions per dimensions provided by us. This holds particularly true concerning the financial aspects within the economy, e.g., in form of economic growth, or taxes. While these are important aspects, we discovered that the students showed a high tendency to focus on these aspects and did not consider others. Thus, depending on the overall setup that the framework is used in, it should be considered to either explicitly remove these aspects, leaving more "novel" aspects as examples, or ask the students for

several aspects within each dimension, thus requiring them to consider other aspects as well. Yet, of course, this comes with an increase of required time resources.

Step 6—the challenge of measuring what matters: The method of developing balanced scorecards is intended to help the students to focus on a certain key aspect in detail and to make the results more tangible. During the course, some of the students had difficulties in expressing the measuring aspects of their suggested ideas. Again, similarly to the challenges arising during the PEST analysis, the students demonstrated a high tendency towards financial measurements. To overcome this, a potential solution could be to have them separately collect a set of, e.g., KPIs from a particular business unit or similar, and then use these to construct metrics for goal assessment. By requiring them to provide more than one metric, the strong focus on the financial aspect can be mitigated.

Step 7—the challenge of pitching the results: Finally, in the last step of the framework, the students had to pitch their overall idea. An interesting observation here was that several groups, although they had a very detailed and narrow set of ideas, fell back to a very generalized presentation of the results and thus were not tapping into the developed potential of their own ideas and ultimately sold themselves short considering their otherwise impressive results. In order to mitigate this, the students were provided with a prestructured template, containing short descriptions that reflect the core steps of the framework and thus helping them to construct a concise presentation. Alternatively, a sub-step could be included that randomly selects groups for peer review, using a rating/scoring catalogue, provided by the lecturers/supervisors. This critical feedback could then be used to further streamline the final results and also to double-check for consistency and understandability to an external audience; again, at the cost of additional time.

5.2. Extensions to the Framework

1. An inherently positive view of digitalization was presented, as a problem solver for sustainability. How about the dark side of digitalization when digital transformation is a problem by itself?

This observation was quite striking and was brought up as we were further analysing the created approaches and solutions by the students. Essentially, every group adopted digital solutions as purely positive artifacts, without discussing unintended side effects of the applied technologies. This is particularly interesting, as they indeed presented a comprehensive overview of challenges and barriers during the task of jointly creating the future scenario 2035. This hints towards the fact that students mostly saw shortcomings of technologies introduced by others, yet not the one they were working with. This could also be to do with the companies and organizations that were used during the course. Although potential bias could already be reduced during the randomization process in the group creation phase, the company or organization representative might, for various reasons, not see or want to see its potential pitfalls. To mitigate this issue, the process could be adapted to not deal with companies or organizations that the students are familiar with or are working in. While this would reduce the potential blind spots, it also puts additional time and resource constraints on the framework, as the in-depth knowledge introduced by the representative is lost and cases need to be carefully preselected to guarantee a smooth workflow during the course. One alternative could be a shuffled review round, in which the groups dissect the elaborated case from another group and try to identify "un-seens" and potential side effects. This also demands for more timewise resources yet could still be achieved in a reasonable amount of time.

2. A micro-level view of digital transformation as an organization-level concern was presented, unlike a system-level transition which, due to the broad adoption of digital technologies, alters social, economic, political, etc. behaviour on a large scale. Can the presented work lend itself to generalization from the micro to the macro view?

From our perspective, yes it can. However, this 'yes' comes with an asterisk. In order to be able to pan out from the micro to the macro view and see the associated benefits, it would be necessary to co-allocate ideas and approaches from companies and organizations

within the same branch, sector, or domain. This would allow for a multiperspective view on existing issues, and thus in turn allow for the identification of beneficial catalysts, synergies, and even threats. However, to be comprehensive, this approach would need to be further extended with additional perspectives of stakeholders that are also involved within the ecosystem to be analysed (see question 3), as well as Member-State strategies concerning the SDGs and their respective national implementation (see question 5).

3. The aspect of micro-sustainability is also viewed from inside an organization. Could an external consumer/partner/supplier view complement the internal view?

The inclusion of an additional business environmental-screening phase can indeed complement the overview; especially when it comes to the identification of key stakeholders [61]. However, at the same time, it also significantly increases the overall complexity and time consumption. The students would be required to construct a kind of interdependency network between their company or organization and the other entities, stating their inherent "mission objective", and also prioritize which of these should be mainly addressed. This requires a lot of expertise and additional information about their environment. Furthermore, while for some stakeholder perspectives, e.g., competitors, the company or organization representatives might have in-depth knowledge from which the group and the entire class (in case it is a global player) can benefit, there might again be also potential conflicts of interest. For example, to reveal critical key stakeholders in the company or organization's supply chain, and what makes them special to the company or organization at hand.

4. Roleplaying could be tried within the framework, including consumer, provider, administrator, policymaker, and other roles, depending on the students' affiliations and professional functions.

Roleplaying can be indeed a powerful tool to reveal perspectives, as well as pros and cons towards a particular issue. Yet, again, in the presented case, this would be very difficult to arrange, considering the number of groups, different branches, countries, etc. Thus, a good approach could be to introduce external people to the study group (e.g., other supervisors, teachers, experts) who can take certain roles, and the study groups can address their questions towards them. Of course, this implies the availability of staff, a budget, and incentives for external persons, as well as suitable premises, in the case of an on-campus course. Having said this, some roles might be easier to fill than others. For example, representatives of a ministry or public administration might be able to address all companies or organizations, while the role of a customer or consumer might be tricky when it comes to B2B or B2C. Furthermore, roleplaying with students should be planned with care and supervised by persons that have experience and education in this domain, as from the authors' experiences, situations can get heated up quite quickly and escalations can potentially ruin the rest of the course due to hurt emotions, mental blocks, etc.

5. Could the national-level SDG review constitute part of the macro/system view on sustainability?

Indeed, the inclusion of national and thus Member-State-level perspectives can introduce interesting impacts into the solutions provided by the students. As discussed before, this perspective could be introduced via roleplaying and/or external experts. That being said, the situation becomes more complex, if—as it is in our case—the companies or organizations are either multinational firms or in general have their headquarters in the different Member States. For example, the students within this case study represented entities from Germany and Austria, thus, at least two different perspectives and national strategies need to be considered. This multiplies according to the heterogeneity of the student groups and their company or organizational representatives.

6. Conclusions

Sustainability is gaining importance in all areas of society. The underlying grant challenges require a broader perspective, building heavily on inter- and trans-disciplinary discourse. In this context, it is the responsibility of higher education institutions to prepare students for this discourse, encouraging them towards the critical reflection of issues of sustainability and sustainable development.

In this paper, we have presented a framework for teaching sustainability in the context of digitalisation and digital transformation. The evaluation of a teaching case study with over 100 students and their results have demonstrated the potential of low-barrier teaching concepts, to not only anchor sustainability teaching into existing curricula, but also to examine how the professional expertise of postgraduate students can be leveraged to work through and solve challenges of sustainability. The lessons learned from this case study support lecturers and supervisors when implementing the presented framework or modified versions of it.

The results of the students have demonstrated how powerful the use of transdisciplinarity in the context of sustainability teaching can be. That being said, the case presented in this paper focuses on a postgraduate programme with professionals as students. The potential for future work lies in a comparative study with classical bachelor's or master's students, identifying differences in results, focal points, and arising challenges. In addition, the presented framework was tested within a sandbox, i.e., the classroom environment. It would be particularly interesting to observe, in a longitudinal study, how the developed ideas could be transitioned into the company or organisational context of the students.

Author Contributions: Conceptualization T.J.L.; Data curation T.J.L., V.A. and C.R.; Formal analysis, T.J.L., V.A. and C.R.; Investigation T.J.L.; Methodology T.J.L.; Project administration T.J.L.; Supervision T.J.L.; Validation T.J.L., V.A. and C.R.; Visualization V.A.; Writing—original draft T.J.L., V.A. and C.R.; Writing—revisions T.J.L., V.A. and C.R. All authors have read and agreed to the published version of the manuscript.

Funding: This research received no external funding.

Institutional Review Board Statement: Ethical review and approval was waived as the case study was part of a regular training programme at the university. These training programmes, such as, e.g., MSc programmes, are regulated by study contracts with the students and therefore do not fall under the remit of the ethics board.

Informed Consent Statement: Explicit participant consent for this study was waived due to defined contractual agreement of every participant (student) as part of their study contract with the university, enabling the university to freely use all work created by its students during the course of their studies, including the use for scientific studies and publication activities.

Data Availability Statement: Not applicable.

Acknowledgments: The first author would like to deeply thank Michael Sachs from Danube University Krems for his support and feedback during the initial phase of the course development. Furthermore, the authors would like to thank Tomasz Janowski from the Gdańsk University of Technology for his reflection on the presented framework and his detailed feedback concerning the sustainability aspects of the presented approach. A big thank you goes also to the students at Danube University Krems for their great support of the lecture and their valuable contributions.

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

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