

Article

Benchmarking a Sustainable Energy Engineering Undergraduate Degree against Curriculum Frameworks and Pedagogy Standards from Industry and Academia

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Abstract: There is an urgent need for educational institutions to produce graduates with appropriate skills to meet the growing global demand for professionals in the sustainable energy industry. For universities to stay at the forefront of meeting this global demand from industry, universities need to ensure their curricula and pedagogies stay relevant. The use of benchmarking is a key means of achieving this and ensuring any gap between university curricula and the practical needs of industry is minimized. The aim of this paper is to present an approach to benchmarking a sustainable energy engineering undergraduate degree with respect to curriculum frameworks recommended by industry and pedagogy standards required and recommended by academia and education research. The method uses the Murdoch University renewable energy engineering degree major as a case study. The results show that the learning outcomes of the renewable energy engineering units, in general, align well with the recommended learning outcomes for a complete sustainable energy degree, as prescribed by the Australian Government Office for Learning and Teaching. In addition, assessment task and marking criteria for the capstone unit of the major were at Australian Universities' standard. A similar approach to benchmarking can be adopted by developers of new or existing sustainable energy engineering degrees in order to align with curriculum frameworks and pedagogy standards required by industry and academic peers.

Keywords: renewable; sustainable; energy; undergraduate; engineering; education; curriculum; pedagogy; frameworks; standards; industry; benchmarking

1. Introduction

There are recent significant changes in the global climate change policy environment that are driving the demand for professionals with sustainable energy skills, particularly across the Asia Pacific region and in Australia. Drivers include the binding international agreements on carbon emissions agreed upon at the COP21 meeting in Paris in late 2015 and the establishment of the \$100 bn per year Green Climate Fund to assist developing countries in emission mitigation practices to counter climate change. The demand for professionals is evidenced by 700,000 new jobs in the global renewable energy sector in 2018 [1]. A number of authors (e.g., [2,3]) highlight the urgent need for educational institutions to be ready to provide appropriate, relevant training to produce graduates with sustainable energy skills to meet the job demand.

In the growing literature on renewable energy education, a number of authors allude to the gaps between university curricula and the practical needs of industry [4–9]. Lucas et al. [10] examine

the impact of the education and training gaps in the renewable energy industries around the world. The authors state that there is an urgent need to address the skills gap as it manifests as a barrier to technology deployment, gives the industry a bad reputation, and/or results in less than economically optimal use of renewable energy. The authors found that there are many higher-education renewable energy (RE) courses that are failing to provide the kind of practical, hands-on training that is required to address the areas where there are skill shortages in the RE industry e.g., construction, installation and operation, and maintenance. Even for RE project manager roles, there is evidence that employers prefer practical experience over e.g., postgraduate RE degrees with specializations in management. The increase in online degree offerings also casts doubt as to whether the students are graduating with enough practical experience.

Comodi et al. [11] state that new ‘green collar’ employees require lengthy and costly periods of induction and professional development because the knowledge and skills taught at University do not meet the requirements of industry. The authors introduce ‘The Crux’ project, an initiative of three European and six Latin American Universities that aims to develop modern content and teaching methods in order to produce “a new type of engineer, with a deeper professional educational background in renewable energy engineering”. Many of the Latin American countries are hiring undergraduate engineers to cope with the increase in the number of renewable energy projects that is occurring due to the rapid modernization and expansion of the sector. The authors distributed a questionnaire on the requirements of the RE industry and received responses from 60 stakeholders with different business activities in the sector. The survey indicated that employers found the knowledge of renewable energy of their current employees was less than satisfactory, particularly those with an undergraduate degree. McPherson and Karney [12] refer to the need to develop “sustainable energy systems thinking” in undergraduates to meet the global challenges of an energy transition from centralized, fossil-fuel driven, utility-based energy systems to decentralized, sustainable, smart energy systems. The authors point out the flexibility that exists in integrating “systems thinking” into the degree and state that fundamental technical units could be augmented by content that cover the political and economic factors that govern the energy system as well as the societal context. This echoes the arguments of Jennings [13] who argues that “modern renewable energy education needs to be an integrated package, encompassing studies of technology, resources, systems design, economics, industry structure and policies, rather than adding a couple of renewable energy elective units to a traditional engineering degree”.

The call for increased sustainable energy graduates applies to many disciplines and education levels. There are several University courses in the area of sustainable energy, the majority of which are postgraduate programs. In 2013, Schneider reviewed the postgraduate programs in sustainable energy that were available throughout Europe [14]. Between 80% and 90% of all graduate and post-graduate courses award a Master of Science (MSc), sometimes with a specialization (e.g., architecture, urban planning, engineering management, etc.) or even a double degree. Thomas et al. reviewed the renewable energy (RE) courses in Australia and New Zealand [15] in 2008 and found that most Universities offer one or two undergraduate units on renewable energy as part of their science or engineering courses but only three Universities offered complete undergraduate degrees in the area of sustainable energy. Not surprisingly, most of the literature on renewable energy or sustainable energy courses relates to postgraduate programs, e.g., [16–18], and literature related to undergraduate sustainable or renewable energy engineering degrees is relatively sparse.

Based on the above discussion, the following research questions arise:

1. What is the range of pedagogies that are being used with undergraduate sustainable energy units, courses, and degrees?
2. Are there existing curriculum frameworks that can be used for benchmarking undergraduate sustainable energy engineering degrees?

The aim of this paper is to present an approach to benchmarking an undergraduate sustainable energy engineering degree with respect to curriculum frameworks recommended by industry and

pedagogy standards required by academia. The approach to benchmarking is relevant for developers of new or existing undergraduate sustainable energy engineering degrees in order to align with standards required by industry, government, and their academic peers. The Murdoch University undergraduate renewable energy engineering degree major is used as a case study in this benchmarking exercise.

The specific objectives of this paper are to:

1. Review the academic literature to find pedagogies that have been used with sustainable energy units, courses, and degrees, so that the design, content, and teaching methods used in a new or existing sustainable energy engineering degree could be placed in the context of this literature.
2. Review the literature to find curriculum frameworks on sustainable energy engineering that have been developed with input from industry and/or government.
3. Use a case study renewable energy engineering degree to explore the value that the processes of internal student review and external academic peer review can have on evaluating and calibrating units within a sustainable energy engineering degree.
4. Use a case study renewable energy engineering degree to benchmark against relevant curriculum frameworks and pedagogy standards.

The paper is structured as follows: Section 2 provides an overview on the materials and methods used in this study. Section 3 presents the results from the literature review and details the case study's review activities. Section 4 is concerned with the benchmarking of the case study against relevant curriculum frameworks and pedagogy standards. Finally, Section 5 concludes and summarizes the findings of the study.

2. Materials and Methods

The study is framed as an evaluative research of the curricula, assessment, and materials from undergraduate sustainable energy engineering degrees and adopts a case study approach using the Murdoch University (MU) renewable energy engineering degree. The following section is provided to give the context of this degree major.

2.1. Case Study: The Renewable Energy Engineering Major at Murdoch University

The Renewable Energy Engineering (REE) Degree at MU was established in 2000 with funding support from the Western Power Corporation and the Western Australian Government Alternative Energy Development Board and was the first of its kind in the world. The funding enabled the employment of a lecturer at MU and the appointment of a range of experts who visited Perth during 2000–2003 and contributed to curriculum and specialized course work material development. The approach facilitated expert knowledge capture at MU and close interaction with academics at the University of New South Wales (UNSW) over several years, which concurrently developed a Bachelor of Engineering Degree in Renewable Energy Engineering [19]. Visiting academics included Stuart Wenham and Hugh Outhred (both from UNSW) and Ralph Sims (from Massey University, New Zealand). Other experts involved in the development of specialized units were academics from MU (Trevor Pryor, Jonathan Whale, and Martina Calais), the Australian National University (ANU, Keith Lovegrove), UNSW (Ted Spooner), and the Queensland University of Technology (QUT, Gerard Ledwich) as well as professionals from industry (Paul Ebert and Craig Carter from Western Power, and Bernie Brix from Westwind Turbines). The first intake of students occurred in 2001, with the first students graduating in 2004. Calais et al. commented on the first experiences of the original REE degree after the first year of its offering and found that “the program attracted highly motivated students from a variety of backgrounds including students from Western Australia, the Northern Territory and Canada” [20]. In 2001, provisional accreditation from Engineers Australia was granted for the Bachelor of Engineering in Renewable Energy Engineering at MU, followed by full accreditation in 2004 with the first graduates entering the workforce in that year. Student numbers grew over the first few years while the degree was being developed with now 20–30 students graduating in the major each year.

The four-year degree was initially developed with a focus on the design and integration of renewable energy systems in grid-connected and micro-grid situations. The degree emphasized design, project management, and familiarity with a range of technologies, which are relevant to the arid temperate zone of Australia. Initially, the degree was delivered at the MU small, regional Rockingham Campus and consisted of a common first year, a core of common engineering subjects (e.g., Mathematics, Economics and Accounting, Project Management and Organization, Law) including the fourth-year Engineering Thesis Project and a suite of specialized REE subjects. Over the years, the REE curriculum and its delivery changed. The University made the strategic decision to move Engineering from the Rockingham Campus to its main Perth Campus and attempted to consolidate areas of strength to improve quality, reach critical mass, achieve efficiencies of scale, and increase competitiveness. Specifically, in Engineering, this led to the development of a common first and second year for several of the engineering specializations in Engineering and allowing students to complete double majors as part of their four-year Bachelor of Engineering degree. Students could choose REE as one of these degree majors. The most recent paper specifically about the REE degree at MU was in 2004 where Calais et al. [21] examined the impact of a curriculum revision that involved mostly traditionally taught units in first and second year, followed by more problem- and project-based units in third and fourth years. Over the years, the number of specialized units in the degree structure was adjusted due to University wide curriculum reviews. The current structure of the REE degree major at MU, which has not been changed significantly since 2016, is discussed in Sections 3.3.1 and 3.3.2.

2.2. Methodological Framework and Data Collection

The methodology used in this research can be summarized in a number of steps. Firstly, a review of the literature was carried out to find relevant frameworks used to design undergraduate sustainable energy engineering courses as well as pedagogical approaches for teaching the courses. In undertaking the literature review, databases were searched using keywords related to the study, e.g., sustainable energy education. Quality of data was a key criterion in the information collection strategies and thus only reputable databases, e.g., ScienceDirect Journals, were used to find peer-reviewed and recent literature. Given the case study approach to the research, importance was given to those frameworks with Australian industry input into the development due to the need to provide industry-ready graduates and to comply with Engineers Australia regarding accreditation of the degree.

The choice of pedagogical approaches to deliver a sustainable energy engineering course is complex. Seatter and Ceulemans [22] highlight the disparate approaches in emphasis and teaching styles regarding sustainability, and the inherently provocative and complex nature of sustainability work. The United Nations Educational, Scientific and Cultural Organization (UNESCO) [23] refer to the requirements for different kinds of models for teaching and learning for sustainability, and that the very nature of sustainability is contested, multilayered, and multifaceted. To further complicate pedagogical choices, while there are numerous papers available on sustainable energy engineering education, the majority discuss curriculum and course content, but have limited information on pedagogical approaches used to deliver that content. To ensure the breadth and depth of the review of pedagogical choices available to use with sustainable energy engineering courses, the approach used in this article was to discuss pedagogies used in renewable energy courses specifically where available, but to also present pedagogical choices from the wider availability of papers for other similar and relevant education areas. For example, this will include pedagogies for capstone engineering units, sustainable development, and sustainability and environmental education. Other relevant pedagogical approaches and instructional methods, such as problem-based learning and jigsaw, are also presented.

Secondly, the REE major at MU was used as a case study of an undergraduate renewable energy engineering degree. The curriculum, content, teaching methods, and accreditation of the REE major were evaluated. As part of the evaluation, examples are given of both an internal student review process and an external peer review process. Student surveys for the unit ENG442 Renewable Energy Systems Engineering (previously ENG421) were considered; since this is a capstone unit for the REE degree

major, all REE students complete this unit and it draws on the content covered in the third-year units ENG337 Applied Photovoltaics, ENG338 Energy Supply and Management, and ENG339 Wind and Hydro Power Systems. In the external process, the ENG442 unit was reviewed as part of a calibration exercise by Innovative Research Universities (IRU, a group of seven Australian Universities including Charles Darwin University, Flinders University, Griffith University, James Cook University, La Trobe University, MU, and Western Sydney University). IRU put in place an Academic Calibration Program, enabling an external peer review process [24]. Specifically, this process enabled a comparable review and constructive feedback for the unit ENG442 (offered in Semester 1 2018) on grades awarded, the relationship between assessment and learning outcomes, the relationship and appropriateness of this unit, within its designated course structures, the clarity and appropriateness of assessment design, learning outcomes, and supporting material for this unit, and the comparison of the assessment and supporting items to that of other IRU institutions [25].

The process was facilitated through designated Calibration Coordinators at each IRU institution, who assisted with finding a suitable calibrator with experience in the discipline and a well-developed sense of academic standards. Once a calibrator was found, several documents were collated, which provided the calibrator with the information for the review. For the specific ENG442 offering, these included:

- Unit Information and Learning Guide provided to students;
- Unit learning outcomes and how they relate to course level learning outcomes;
- Unit grade distribution;
- Details of the design project (see also Sections 3.3.3 and 3.4.1), which was chosen as the representative assessment item for this unit as it is worth 40% of the assessment and covers most of the unit learning objectives. Students performed this project typically in groups of four and were asked to design a roof-mounted, grid-connected PV system. The system had to include battery storage for maximizing the self-consumption of PV generated electricity for the chosen application.
- De-identified student assessment samples over a range of grades (these were associated with the group project and included the design proposal, detailed electrical design drawings with an associated report, and a presentation on the proposed design including a cost and performance estimation for the proposed system/installation);
- Marking criteria of the design project assessment components;
- Course level learning outcomes and course structure;
- University grading nomenclature.

Finally, benchmarking of the case study REE degree was carried out by comparison of the REE pedagogy with the literature, a qualitative analysis of the comparison of the recommended learning outcomes from REE units with relevant industry/government curriculum frameworks, and by comparison of curricula of the REE degree major and overseas undergraduate sustainable energy engineering degrees. An overview of the methodology used in this research is provided in Figure 1.

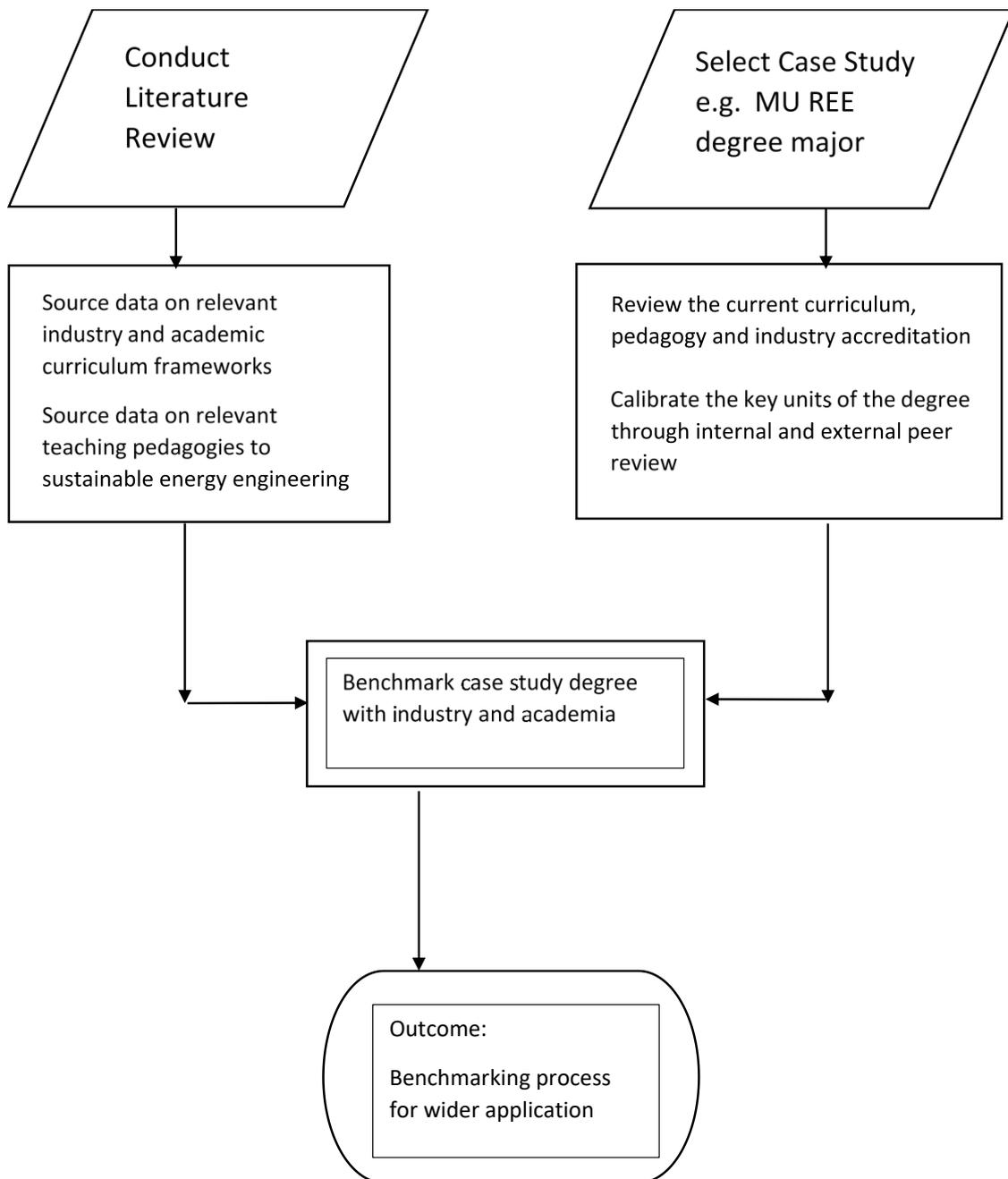


Figure 1. Flowchart showing the methodology of the research.

3. Results

3.1. Pedagogies Relevant to Sustainable Energy Units, Courses, and Degrees

Many papers that discuss sustainable energy engineering education focus on course content but have limited information on pedagogical approaches used to deliver that content. To ensure breadth and depth of pedagogical approaches discussed, this paper includes pedagogical approaches for sustainable (renewable) energy education specifically, but also pedagogical approaches that are considered relevant from other related education areas. This section is broadly written to start from specific and expand into more general, and includes pedagogical approaches from the following educational areas:

1. Renewable energy education specific;
2. Capstone engineering units;
3. Other relevant pedagogical approaches and example instructional methods;
4. Sustainable development, sustainability, and environmental education.

3.1.1. Renewable Energy Education Specific

Literature on renewable energy education recommends a focus on deliberate and integrated practical aspects to encourage students to learn through doing, based on principles of Kolb's experiential learning theory [26]. Kandpal and Broman [8] recommend renewable energy education provide a balance between theory and practical aspects, and should include laboratories, practical demonstration of operational systems, field visits and field installation of actual working systems, and hands-on-skills training such as trouble-shooting, design, and manufacture besides lectures, tutorials, assignments, and seminars. This is echoed by Svirina et al. [27], and the notion that high-quality education in the field of renewable and alternative energy processes requires a balance of internships, simulations and laboratory works, and some lecturing. Practical work and face-to-face or blended learning were considered important as modes of instruction for the first degree as found by Lund et al. [28]. Friman [29] presents a teaching method that combines two approaches used to teach renewable energy, where individual, independent, physical work with equipment is combined with virtual results analysis, drawing conclusions, and testing on the computer. Stroth et al. [3] refers to a blended learning approach based on the concepts of active and cooperative learning, and broadly on the experiential learning theory as described by Kolb [26]. The core approach to teaching behind Kolb's learning theory is that people learn best through experience, and this approach is echoed throughout renewable energy education.

Beyond an experiential learning approach, links with industry and work are also recommended. Work integrated learning was identified by Lund et al. [28] as one of the favored teaching approaches for sustainable energy education. The importance of collaboration with industry was highlighted by Lucas et al. [10], as well as the need for sustained efforts towards deploying quality standards in RE education and training, which ought to be developed in close cooperation with the industry. Further to industry cooperation, Gutiérrez et al. [30] highlight diversity's potential as an enhancement factor for the pedagogies in renewable energy education, and notes that a diverse structure in the study program can widen the options for the students' career paths. Wider career paths increase the opportunity for links with industry beyond graduation, further linking renewable energy education with industry and work. This all highlights the need for inclusive pedagogy and strong links with industry to encourage the forming of a strong community of practice in the context of Wenger's social theory of learning [31,32] surrounding renewable energy within the university and beyond into industry.

3.1.2. Capstone Engineering Units

Engineering courses, including renewable energy, will have a capstone unit, or at least one or multiple units that act as a capstone unit. The capstone unit(s) occurs at the end of the course and helps to summarize and reinforce the learnings from the course while supporting the student's move into industry. This creates unique requirements for capstone units and the choice of pedagogical approaches used for capstone engineering units is important to ensure this final stage of a renewable energy engineering course is most effective.

Capstone units represent a critical transition between study and work, and support student's transition from student to professional in the context of Wenger's [31,32] social theory of learning. Pembridge et al. [33] presents a taxonomy of capstone engineering units, describing teaching in the context of the capstone design course as students learn not only to "do design" but also to "be engineers" in ways that encompass a full range of professional practices. Pembridge's study is informed particularly by Lave and Wenger's [34] theory of legitimate peripheral participation, which considers learning as "an integral and inseparable aspect of social practice". Capstone engineering units must

combine the complex process of design teaching with the equally complex process of socializing students to professional engineering practice [33]. Capstone units represent a critical transition between study and work, and support student's identity transition from student to professional in the context of Wenger's [31] social theory of learning. Pembridge et al. suggest capstone units require students to apply life-long learning, engineering judgment, analytical decision-making, and critical thinking to address complex problems under a spectrum of social, environmental, and economic constraints. At the heart of capstone units, faculty participants of the Pembridge et al. study described intentionally creating, soliciting, and shaping projects that will challenge students to help them develop as engineers and prepare them for the workforce. To do so, students are provided with projects intentionally designed to meet three practices:

- Integrate previous learning;
- Prompt new learning;
- Provide realistic experiences that address full project cycles, incorporate authentic constraints, and are open-ended.

To accomplish this, the Pembridge et al. study [33] provides the below taxonomy of five curricula and pedagogical principles (referred to as Pem1, Pem2, Pem3, Pem4, Pem5, respectively, later in this paper) that can be utilized to support the transition from student to professional and enhance students' holistic professional preparation:

1. Beyond design into norms and expectations of profession;
2. Challenge but protect from project and learning failures;
3. Faculty act as role models—mix engineering teachers with engineering managers;
4. Guiding students as opposed to direct instruction;
5. Highly relational teaching, including individual engagement.

Capstone units prepare students for engineering workplaces, and Pembridge et al. suggest that capstone faculty themselves must serve as role models of practicing engineers and this is particularly salient for capstone units. Capstone faculty must learn to balance acting as engineering teachers to facilitate learning and acting as engineering managers to model professional workplaces. In addition to acting as engineer role models, to support the transition to work, faculty need to balance practices that challenge students with practices that protect them from project and learning failures. Such protection requires substantial attentiveness from faculty with respect to both the progress of the project and the dynamics of the team [33]. The nature of capstone units taught in this way and the ability to help students learn relevant professional skills can assist students to remain competitive for their future career. Kumar [35] refers to the competitive global market and changing work environment that demands engineers possess "soft skills" in addition to technical skills. While this should be the goal of all units across an engineering course, this is particularly relevant to capstone units in the context of Pembridge's study.

Further to capstone teaching, Meyers and Nulty [36] refer to five principles that can be used to maximize the quality of student learning outcomes across any course. They suggest course designers need to develop courses in ways that provide students with teaching and learning materials, tasks, and experiences, which apply these principles (referred to as MN1, MN2, MN3, MN4, and MN5, respectively, later in this paper):

1. Are authentic, real-world, and relevant;
2. Are constructive, sequential, and interlinked;
3. Require students to use and engage with progressively higher order cognitive processes;
4. Are all aligned with each other and the desired learning outcomes;
5. Provide challenge, interest, and motivation to learn.

The effect of applying these principles, according to Meyers and Nulty, is to manipulate the learning system in ways that require students to adopt a deep learning approach in order to meet the course's assessment requirements—which, in turn, meets the desired course learning outcomes. Individual curricula innovations that relate primarily to any one of the five principles generally also relate to one or more of the others. Thus, thinking of them serially is artificial and would result in repetition. Instead, the deliberate sequence of the course teaching, learning materials, and tasks is relevant, which create the journey of discovery that the students themselves will experience. In this way, the combination of curricula innovations address the five principles, and result in students' willing participation, and obligates students to engage in higher order cognitive processes during the course, and that this cognitive-behavioral response is entirely consistent with the achievement of the course learning aims [36]. It should be noted that the five principles discussed above (MN1 to MN5) have influence on both curriculum content and pedagogical approach, and when applying to the design and delivery of a course (such as a capstone unit) would be strongly linked.

3.1.3. Other Relevant Pedagogical Approaches and Example Instructional Methods

To further support the development of relevant professional engineer attributes and maximize student learning, there are broadly used pedagogical approaches or instructional methods that significantly increase student's learning of skills relevant to this. These approaches can also help faculty manage the balance of challenge versus safety as per principle Pem2 above.

Problem-based learning is a specific teaching approach that has been used in medicine for many years in differing forms as described by Barrows' taxonomy [37] and according to Kumar and Radcliffe [38] can also be useful in engineering. Perrenet et al. [39] suggest that problem-based learning offers good prospects in the first few years of a program, especially if group work tutorials and some directive teaching are added, and as a strong alternative in later phases of project work. Lutsenko's [40] case study clearly demonstrates that implementation of the problem-based learning can be a useful approach for the development of the students' skills such as self-directed learning, ability to apply knowledge in practical situations, teamwork, and project management in engineering students. The findings of the study also highlighted that students show a positive attitude to the problem-based learning experience including different aspects of the learning process, methods of assessment, teamwork and connection between projects, and their future professional activity. The benefits of problem-based learning support the use of this teaching approach within renewable energy engineering.

A second relevant specific teaching approach is jigsaw, which can be used to encourage students to learn a topic and then peer teach it to their fellow students. Barkley et al. [41] provides details of a variance of jigsaw, which allows for whole-of-class discussion following the jigsaw activity, and another variance where the entire jigsaw activity is done on a whole-of-class basis. Hensley [42] provides an example of a lesson where students compare renewable and fossil fuel energy technology options using jigsaw, with a focus on externalities and interlinking of sustainability factors for the various technologies. Jigsaw is a teaching method that encourages peer reciprocal teaching and its recommended use by Hensley to teach what is effectively a renewable energy sustainability lesson, supports the use of jigsaw in renewable energy engineering education.

Based on review of 157 learning designs across 60,000+ students using learning analytic approaches as a means to evaluate the impact of pedagogical decision making, Toetenel et al. [43] found a negative correlation between an extensive use of assimilative activities and student outcomes, further supporting the need for active student involvement in classes and a move towards student-centered group teaching, such as problem-based learning and jigsaw mentioned above. Further to this, teaching activities that go beyond technical skills are relevant to all engineering courses including sustainable energy. Problem-based learning can be used to develop work-ready "soft skills" as encouraged by Kumar [35], and to develop deeper learning, problem-solving abilities, teamwork, and self-directed learning capabilities as highlighted by Kumar and Radcliffe [38]. UNESCO [23] also suggest that sustainability

provides rich opportunities for critical thinking and transformative learning, which further supports the use of teaching activities that encourage non-technical skills such as those developed in group-work based pedagogical approaches such as problem-based learning and jigsaw.

As recognized by Barkley et al. [41] and others [38,39], group work can have potential problems for faculty and students, but there are various means of helping to address them. Firstly, lessons should be designed with potential problems in mind to minimize the chance of problems arising for students or faculty in the first place. Barkley et al. [41] has broad principles to follow for group work lesson design, and depending on the specific teaching approach used, other sources have specific guidance for individual instructional methods (for example, Hensley [42] has suggestions for jigsaw). Secondly, should problems still arise during the lesson or course, Barkley et al. [41] provide specific guidance on how to address 10 common problems with group work. For example, for resolving group conflicts, Barkley et al. suggest a range of problem-solving strategies with differing levels of teacher interference or presence, including individual student and group consultations, exercises for collaborative skills development, sharing examples of effective behavior, and facilitation of group orientations where students are involved in establishing ground rules and take on ownership and responsibility for observing and enforcing their rules. Reorganization of groups is only considered as a last resort. This guidance on minimizing potential problems with group work can help to maximize effectiveness of using group work in renewable energy engineering education.

3.1.4. Sustainable Development, Sustainability, and Environmental Education

Sustainable development has many unique challenges inherent in the subject, and to help students navigate this in their future life, the development of critical thinking abilities during sustainability-related university courses is encouraged. UNESCO [23] refer to the need for different kinds of models for teaching and learning to meet challenges of sustainable development education and highlights that the goal of higher education is to support students in developing their capacity for recognizing and understanding the complexity of sustainability issues, and for thinking critically. The very nature of sustainability as a contested, multilayered, and multifaceted subject provides rich opportunities for critical thinking and transformative learning [22,23]. Holt et al. [44] suggest the most effective strategies to promote student critical thinking include alignment at a high Bloom cognitive level [44,45] using learner-centered in-class activities, and well-balanced learning objectives and assessments. Pappas et al. [45] refer to strong indications that students are now increasingly able to employ a systems approach to sustainability in their engineering courses and projects, using a Bloom's developmental approach. Discussing how sustainable development learning outcomes can best be achieved in engineering through the use of the most appropriate pedagogical strategies, Segalàs et al. [46] found that better cognitive learning outcomes are achieved when students are exposed to more community-oriented (offering a transdisciplinary perspective) and constructive learning approaches, which also facilitate systemic and critical thinking. Segalàs et al. [46] also noted the tendency to focus on technological solutions to environmental problems of students surveyed and recommend that more emphasis should be placed on the social and institutional aspects of sustainability in engineering education. Further, Nagel et al. [47] want students to be able to negotiate the sometimes treacherous waters of professional practice that include being sensitive to the conditions that promote both human and technological progress, and at the same time, possess a conscience that directs their careers and personal lives. This is all highly relevant for renewable energy engineering courses, where future engineers will be directly assisting the global society to address the complex problems associated with energy and climate change. This will require significant critical thinking abilities relating to sustainability.

Further to critical thinking skills, all engineers require other competencies relating to sustainable development. Holgaard et al. [48] refers to the Stage 1 Competency Standard of Engineers Australia, which defines those outcomes that a graduate should be able to demonstrate at the end of their university education as part of course accreditation. Several of these competencies relate to sustainable

development. The link between required student competencies and appropriate pedagogies to promote student learning in those capabilities is important. Segalas et al. [46] suggest sustainable development courses within engineering should apply a constructive and community-orientated pedagogical approach. Lozano et al. [49] analyzed competences and pedagogical approaches, using hermeneutics to connect these in a framework. This framework can help faculty choose pedagogical approaches that are specifically aligned with sustainability related competencies to maximize student learning.

Of relevance to suggested pedagogical choices is that project-based, problem-based, and case-study-type teaching strategies were all highlighted as providing a contribution to sustainable development education in engineering. Negal et al. [47] recommend student-centered design studio learning, real-world application projects, collaborative design, and problem-based learning. Holgaard et al. [48] further confirms the use of problem-based learning and its effectiveness at assisting students learn sustainability-related competencies such as critical thinking. Further to this, Brundiens and Wiek [50] suggest a hybrid form of problem- and project-based learning in the context of sustainability education. They suggest courses in sustainability adopt the problem inquiry as in problem-based learning and, in order to develop solution options, the product-orientation from project-based learning. Combining both approaches aims at avoiding both the risk of getting caught in the knowledge-first trap by endlessly analyzing problems, as well as jumping prematurely to solutions without sufficient problem framing and analysis [50]. This confirms the use of problem-based or hybrid learning in renewable energy engineering.

Problem-based learning can be an attempt at making student learning activities more real-world, and Brundiens et al. [51] suggest that real-world learning opportunities can align well with key competencies in sustainability. However, they note that students do not automatically build competencies when engaging in such opportunities and refer to the need to incorporate three principles to be effective: Collaborative design, coordination, and integration in general introductory courses. Lozano et al. [49] support this and refer to the need for systems thinking and interdisciplinary approaches, and pedagogical innovations that provide interactive, experiential, transformative, and real-world learning when integrating sustainable development competencies into curriculum. This all confirms the use of coordinated interactive, experiential, real-world learning as can be achieved using well-designed and -managed problem-based type learning.

To summarize this section, Seatter et al. [22] makes a strong statement regarding sustainability: "Today's students need to be able to recognize the unsustainability of contemporary problem solving, cease searching for the "one right answer," and think instead in terms of good ideas and best solutions. They need to overcome the paradox of a powerful sustainability message framed within a powerless pedagogy." This highlights the importance of teaching students to think critically and echoes Byrne [52] who suggest a critical educational goal must be to help students improve the skills and mindsets that will enable and motivate them to become socially and environmentally responsible and engaged problem-solvers and citizens. Byrne suggests that a teaching-centered paradigm is inadequate to achieve these crucial learning outcomes, especially given the high societal risks associated with failing to help students achieve higher levels of environmental literacy. Further, the best available scientific evidence indicates that learner-centered teaching approaches have higher efficacy for helping students achieve long-lasting, meaningful, and significant learning gains, and a strong learner-centered teaching paradigm is a necessity for helping students become highly knowledgeable and skilled sustainability leaders [52]. In support of this, Dyer [53] discusses a STEAM-based strategy for educating creative engineers to support creative problem-solving as specified by many of the Graduate Attributes required by the Washington Accord, for accreditation of tertiary engineering degrees. The approach refers to a multi-disciplinary framework coupled with pedagogical practices from the Arts and Design that focuses learning on the human sciences, natural sciences, craftsmanship, and design thinking to provide holistic engineering education underpinned by technical competencies. This all provides further support to the inclusion of student-centered pedagogical approaches that encourage the development of self- and critically reflective problem-solving skills in renewable energy engineering students.

3.2. Nationally Recommended Frameworks for Sustainable Energy Curriculum

The literature review found that the most relevant framework for benchmarking the MU REE degree major comes from a set of curriculum frameworks presented by the Australian Government Office for Learning and Teaching in a 2014–2015 federally funded Office for Learning and Teaching (OLT) study “Renewing the Sustainable Energy Curriculum—Providing Internationally Relevant Skills for a Carbon Constrained Economy”. The study showed a gap between sustainable energy curricula taught across tertiary education institutions and the expectations of industry and graduates [54]. The OLT project was a benchmarking study for all sustainable energy courses across Australia, including undergraduate degrees, and involved representatives from some of Australia’s leading Universities in this area including MU, ANU, UNSW, QUT, and the University of South Australia (UniSA). The project was the first coordinated study of the knowledge, skills, and generic graduate attributes needed by tertiary trained sustainable energy professionals in Australia and involved the incorporation of these requirements into curriculum frameworks that are internationally relevant.

The OLT study [54,55] developed a set of curriculum frameworks for various levels and types of degrees. The appropriate framework for the MU REE major is that recommended by the OLT study for undergraduate Bachelor of Engineering degrees with a specialization in renewable energy systems.

Table 1 displays the suggested advanced level curriculum framework learning outcome maps for program coordinators and unit coordinators in the planning and development of an undergraduate Bachelor of Engineering degree with a specialization in renewable energy systems. The advanced level learning outcomes are an appropriate level for comparison with the REE degree major of units, since these units are taken in the third and fourth years of the degree.

Table 1. Recommended advanced learning outcomes for a BEng (renewable energy (RE) Systems) from the Office for Learning and Teaching (OLT) Study (adapted from [54,55]).

| Leadership, Ethics, Engineering Application Ability, Professional and Personal Attributes | | |
|---|--|---|
| <ul style="list-style-type: none"> • Be able to perform strategic management—the management of both human and financial resources. • Be able to describe the law—as it relates to contract and tort, copyright, and intellectual property. • Be familiar with and uphold ethics—specifically, demonstrate knowledge of the engineering code of ethics and its operation in engineering practice. • Be able to exercise professionalism and understand the roles and responsibilities of the professional engineer | <ul style="list-style-type: none"> • Be able to analyze, examine, and report on a research or design problem and to demonstrate a level of mastery of the subject area; • Be able to apply the necessary design practice and undertake research to produce the outcome or solution for a set task, and • Present and communicate results and findings verbally and in written form. <p style="text-align: center;">Recommended learning activities to achieve above outcomes are listed below:</p> <p>Thesis 1 Exposure to, and experience with, a significant engineering project, with emphasis upon industrially based projects. Involves elements of specification, design, implementation, testing, documentation, demonstration, and presentation. <i>or</i> Internship 1 Exposure to industrial engineering projects involving elements of specification, design, implementation, testing, documentation, demonstration, and presentation. Prepare a project report, deliver seminars describing the project, and attend meetings with academic and industry supervisors as required.</p> | <p style="text-align: center;">Thesis 2</p> <p>Thesis 2 can build on and extend Thesis 1 or be a separate project with similar learning outcomes <i>or</i> Internship 2 Internship 2 can build upon and extend Internship 1 or be a separate project with similar learning outcomes</p> |

Table 1. Cont.

| Advanced RE Systems 1—Solar Photovoltaic | Advanced RE Systems 2—Solar Thermal | Advanced RE Systems 3—Wind Energy |
|--|--|---|
| <ul style="list-style-type: none"> • Be able to calculate the position of the sun, the incidence of solar radiation on a plane, and the available solar resource • Be able to discuss common applications for stand-alone and grid systems • Be able to describe components of either a stand-alone or grid-connected photovoltaic system. • Understand the process of designing, commissioning, and testing simple PV systems including: <ul style="list-style-type: none"> ○ Simulation and system design; ○ Component sizing, housing, and layout; ○ Cabling and earthing; ○ Commissioning and testing; ○ Monitoring; and ○ Safety and standards | <ul style="list-style-type: none"> • Have a good understanding of the techniques for exploiting solar radiation for thermal applications at low, medium, and high temperatures. • Be able to specify, design, and install solar thermal systems • Understand and explain the characteristics of solar radiation, selective surfaces, and heat exchangers. • Be able to specify and design low-temperature applications—water and space heating. • Be able to specify and design absorption chillers. • Be able to specify and design medium temperature applications—process heat for industry • Be able to specify and design high temperature applications—steam cycle electricity generation, solar chemistry. • Be able to specify and design thermal storage systems. | <ul style="list-style-type: none"> • Have a good understanding of the engineering aspects of wind energy technology including: <ul style="list-style-type: none"> ○ Wind monitoring; ○ Design, manufacture, and performance of wind turbine components; ○ Power conditioning; ○ Control and safety ○ Planning, design, and installation of wind farms and small wind systems; ○ Environmental and social issues. • Be able to design and calibrate a wind monitoring system. • Be able to analyze recorded wind data and predict long term wind behavior • Be able to analyze the performance of a wind turbine • Understand the design aspects of the installation of a small wind system • Be able to design the layout of a wind farm subject to environmental and social constraints |

Table 1. Cont.

| Advanced RE Systems 4—Bioenergy | Advanced RE Systems 5—Remote and Micro-grid RE Systems |
|--|--|
| <ul style="list-style-type: none"> • Have a good understanding of what ‘biomass’ and ‘bioenergy’ are and the various forms of biomass materials. • Know how to identify and quantify different biomass resources, including: <ul style="list-style-type: none"> ○ Woody biomass; ○ Non-woody biomass; and ○ Dry and liquid waste. • Be familiar with the biomass supply chain including harvesting, transport, and processing. • Have an appreciation of the complexities and costs associated with biomass delivery. • Have an understanding of biomass processing and the transformation of biomass into bioenergy. This includes: <ul style="list-style-type: none"> ○ Thermal biomass conversion; ○ Biochemical conversion of waste biomass resources; and ○ Landfill gas utilization. • Be familiar with biomass feedstock suitable for biodiesel, bioethanol, biogas, and bio-oil and understand the production process for biofuels. • Have an understanding of the limitations of various conversion technologies for transforming biomass into useful energy products (heat, power, electricity, transport fuels). • Understand the concept of using biomass fuels to displace fossil fuels and be able to highlight the environmental and social aspects of using biomass for energy purposes. | <ul style="list-style-type: none"> • Be able to describe the typical components of a Remote Area Power Supply (RAPS) system. • Be able to discuss different types of RAPS systems and, in each case, describe the typical features of the system load profile. • Be able to discuss the advantages and disadvantages of diesel hybrid systems and describe the operation of these systems. • Be able to sketch and describe the different configurations of diesel hybrid systems and describe the operation of these systems. • Be able to calculate the daily performance of different hybrid systems by analyzing the hour by hour operation of these systems. • Understand the process of designing, commissioning, and testing of RAPS systems including: <ul style="list-style-type: none"> ○ Simulation and system design; ○ Component sizing, housing, and layout; ○ Cabling and earthing; ○ Commissioning and testing; ○ Monitoring; ○ Safety and standards. • Be able to use computer programs to estimate the performance and economics of RAPS and micro-grid system |

3.3. Design, Content, and Teaching Methods Used in the MU REE Degree Major

3.3.1. MU REE Curriculum Design and Structure

The Bachelor of Engineering (Honors) with the major in REE is accredited by Engineers Australia (EA) and as such is designed to ensure the graduate outcomes for EA are met within the degree. The current structure of the Bachelor of Engineering Honors degree with the major in REE at MU is available on the course website [56]. As mentioned in Section 2.1, the current curriculum design features the first two years common between four of the major disciplines of engineering at MU and a suite of five REE specialization units in the third and fourth years [57–61], which are listed in Tables 2 and 3. As the structure allows for a combination of two engineering majors aligned with the same degree structure, the majority of REE students graduate with a double major. Combinations are possible with Industrial Computer Systems Engineering (ICSE), Instrumentation and Control Engineering (ICE), and Electrical Power Engineering (EPE). The EPE/REE combination is the most popular followed by ICE/REE and only a few students selecting ICSE/REE. The latter combination is more suited to part-time students since the completion of the degree within four years is challenging due to the specialized units of these majors only being available in a certain semester pattern. A few students have also completed a double major with Environmental Engineering, but this choice required more than four years of full-time study. Planned recent adjustments to the structure of the Bachelor of Engineering Honors degree at MU also enable this combination of majors within the four-year timeframe in future.

The four-year degree has an embedded Honors project [62], which students conduct in their final year, and is worth 12 credit points. This 12-point unit, together with 28 units of 3 credit points, makes up the 96 points required for completion of the degree.

3.3.2. MU REE Degree Major Content

The main learning outcomes of the five specific REE units are shown in Tables 2 and 3. The content of most of these units is centered on specific RE technologies. ENG442 is the capstone unit of the REE major as it brings together knowledge of various technologies and focuses on the design of systems featuring these technologies. The content has strong industry relevance using international design, safety, and performance standards, recommended and best practices, and industry-relevant software. Guest lecturers from industry, including with case studies from the field, enhance the element of industry alignment.

Table 2. Main learning outcomes from the current third-year Renewable Energy Engineering (REE) units (Source: [57–59]).

| ENG337 Applied Photovoltaics | ENG338 Energy Supply and Management | ENG339 Wind and Hydro Power Systems |
|--|--|---|
| On successful completion of the unit you should: | At the end of this unit, students should be able to: | Upon completion of this unit student should be able to: |
| <ol style="list-style-type: none"> 1. Have gained a thorough understanding of the requirements, composition, operating principles, testing, fault finding, monitoring of and performance experiences with PV systems and PV system components. 2. Be able to design and specify stand-alone PV systems, perform resource and load assessments, and select and size system components. 3. Be able to explain installation and equipment requirements. 4. Work and communicate effectively within a group. | <ol style="list-style-type: none"> 1. Demonstrate an understanding on the various technologies used in electricity and heat generation, their current status of development, and key issues. 2. Explore Energy Management Systems and investigate some of the tools and techniques involved in Energy Management Programs. 3. Analyze the economic viability of energy management options. 4. Apply advanced technical knowledge and approaches in designing and sizing Wind and PV systems. 5. Communicate effectively as part of an engineering team and contribute in designing a project. Where a group has been formed, communicate and perform effectively as part of an engineering team. 6. Apply problem solving and research skills as part of developments of energy audit systems. | <ol style="list-style-type: none"> 1. Conduct a wind resource assessment using both experimental measurement and computational simulation. 2. Demonstrate their knowledge of the aerodynamic and mechanical loads on wind turbines and explain how this knowledge is used in the design and manufacture of wind turbines. 3. Discuss different power configurations of wind turbines as well as different methods to control wind turbine operation. 4. Discuss the key aspects involved in planning, designing, installing, and operating wind farms. 5. Demonstrate familiarity with the approaches used in conducting a resource assessment for a potential hydropower installation. 6. Size a micro hydro system for a particular resource and load and give recommendations for the type of system required. 7. Discuss the issues involved with integration of hydro systems on an electricity grid. |

Table 3. Main learning outcomes from the current fourth-year REE units (Source: [60,61]).

| ENG441 Solar Thermal and Biomass Engineering | ENG442 Renewable Energy Systems Engineering |
|---|--|
| <p>On successful completion of the unit you should:</p> <ol style="list-style-type: none"> 1. Understand fundamentals of solar thermal and biomass engineering systems; 2. Understand typical applications of solar thermal, and biomass biochemical and thermochemical conversion technologies; 3. Apply the fundamental and technical knowledge acquired in this unit in designing and conducting relevant engineering projects on solar thermal and biomass conversion; 4. Communicate your ideas and proposals related to solar thermal and biomass conversion at an engineering level; 5. Discuss environmental sustainability and techno-economic performance of relevant projects on solar thermal and biomass engineering; and 6. Accumulate essential knowledge in conducting research studies on solar thermal and biomass conversion. 7. Work and communicate effectively within a group. | <p>On successful completion of the unit students should be able to:</p> <ol style="list-style-type: none"> 1. Apply design processes and understand installation requirements and standards of photovoltaic systems and their components; 2. Analyze technological, regulatory, and economic aspects of wind energy conversion systems integration into existing power systems. 3. Contribute to a design project and communicate effectively as part of an engineering team. |

3.3.3. Teaching Methods Used in the MU REE Degree Major

A variety of teaching methods and styles are used in the major's REE units. These range from direct instructions in lectures and demonstrations (teacher-centered styles), to guided and interactive problem solving in tutorials, guided learning in a laboratory setting, and problem- and inquiry-based learning through facilitation of group project work (student-centered styles).

This range is reflected in the delivery and assessment of the REE units, which typically include two hours of (recorded) lectures, one hour of workshop, and three hours of laboratory per week. The assessment structure typically includes laboratory and site visit assessments, project work (worth 20%–40% of the final mark), and a final examination (worth 30%–50% of the final mark). Semester tests and quizzes may also be included.

Laboratory activities expose students to a diverse range of practical, simulation, and design exercises, for example exercises around wind and solar resource assessments and environmental parameter monitoring, IV curve measurements of PV modules, using industry-standard software to simulate a PV, Diesel, Battery Hybrid system, determining the heating value of biomass using a calorimeter, and efficiency measurements of solar thermal systems.

Where possible laboratory activities are inter-linked with other teaching activities, for example, students perform soil resistivity tests and earth electrode measurements as part of a laboratory of the unit ENG442. A lecture presenting a case study of a wind farm earthing system design and associated commissioning tests relates these laboratory activities to real-world engineering activities. A workshop provides the opportunity to compare laboratory results taken at different times and conditions during the semester, and finally two lectures given by industry professionals provide further insight into the development, planning, and technology of the wind farm introduced in the earlier case study.

Further professional engineering practice-related activities provide students with real-world experiences that underline the relevance of the knowledge and skills obtained during their major. The application of standards and industry guidelines is emphasized in laboratories and project work. Industry guest lectures, excursions, and incursions expose students to practical engineering aspects of a variety of renewable energy engineering projects, systems, and installations. Some examples include the demonstration of lowering and maintaining a small wind turbine, site visits to algae ponds and photobioreactors, a wave energy plant, chillers, building management systems and energy efficiency initiatives on campus, wind farms, and a variety of solar PV installations.

Industry and research expertise of staff teaching in REE units is being shared in a wide variety of teaching activities and is associated with renewable energy system integration, inverters, small wind turbine testing, biofuel production using microalgae and quality assurance, fault diagnosis, and testing of PV modules. For example, the unit ENG337 Applied Photovoltaics includes teaching activities around photovoltaic metrology, where students observe and evaluate PV module tests on MU's Class A+ Sun Simulator.

Project work is firmly embedded in all REE units, well aligned with unit content and learning objectives, and often interlinked with other learning activities. For example, for the unit ENG338 Energy Supply and Management, the project requires groups of students to perform a detailed energy audit for one or two of the University's buildings. For these audits, students collect data and use data from the University's building management system, which they already encountered during the unit's site visit. Further project activities are investigations into consumption level reductions and suitable renewable energy system designs to substitute the energy demand of the building.

Project assessment typically consists of several staged assessment items and feedback processes to guide students during their project activities. They may include risk assessments of project-related site surveys, followed by a preliminary design before a more detailed design documentation is produced, once feedback on the preliminary design has been reviewed and addressed. Class presentations and discussions of final designs (or project findings and recommendations) and cooperative learning activities during group project work provide students with many opportunities to develop generic

skills (critically review, analyze, and evaluate designs and work of others, teamwork, collaboration, self and time management).

Project work progressively introduces students to higher-order cognitive processes, more complex tasks, and expands their knowledge and skills. For example, a third-year group project in the unit ENG337 Applied Photovoltaics is centered around the design of a small standalone PV system to power DC loads of a ticket parking machine for specific locations on the MU Campus, requiring students to perform site specific solar resource assessments, battery sizing and charge controller, and balance of system component selections (drawing on skills and content students have been introduced to in the unit ENG337). The project also draws to a limited extent on skills obtained in the predecessor unit ENG338 Energy Systems and Management (load profile estimations). The group project in the capstone unit ENG442 in fourth year is more involved, complex, and challenging. It requires students to produce a detailed electrical design for a grid connected PV system (less than 30 kW) with battery storage at a location of their own choice, incorporating measures that protect the installation against the indirect effects of lightning strikes. The design exercises require students to apply several relevant standards and guidelines, produce technical documentation that is typically supplied to customers upon project completion, and asks for an industry-standard software simulation to estimate the systems performance. The ENG442 group project hence builds on skills and content not only obtained from the unit ENG442 itself, but from a variety of foundation engineering units and ENG337 and ENG338.

3.4. Evaluation of the MU REE Degree Major to Date

3.4.1. ENG442 Unit Surveys

The capstone unit ENG442 Renewable Energy Systems Engineering focuses on grid-connected photovoltaic and wind energy systems, however remote wind-diesel systems and design processes applicable to stand-alone systems are also discussed. The unit deals with the integration of renewable energy generation into existing power systems covering technical and regulatory issues. Learning activities and laboratory sessions expose students to a variety of practical tasks and demonstrations such as fault finding in a PV array, measurement of leakage currents in a transformerless grid-connected PV system, arcing in DC systems, and control and operation of a stand-alone PV/Wind/Battery/Diesel Hybrid system. Power system simulation and design and economic evaluation exercises complement the practical activities and in the last few years, students participated in a site visit to major wind and PV installations in WA, visiting the 10 MW Greenough River Solar Farm and the 55 MW Mumbida Wind Farm. The unit incorporates a major renewable energy system design group project with several assessment items (see also Section 3.3.3 above). Students are also assessed on participation, documentation, and presentations on laboratory, site visit and guest lecture activities and sit a final exam.

In the past few years, this unit has been consistently ranked highly in unit surveys by students at MU. Unit surveys for ENG442 and its predecessor unit ENG421 have been reviewed for 2013–2016, and 2018–2019 (for 2017, no data are available). These surveys were administered by a centralized team in the University, to ensure anonymity for students who respond and to maintain the accuracy and validity of the survey process. Students undertake the survey at the end of the semester and are encouraged to participate. Response rates of the surveys varied from year to year. Most survey response rates were close to the average response rate for this group of surveys of 42.5% (2013: 35.3%, 2014: 42.3%, 2015: 40%, 2016: 42.1%). In 2018, the response rate was low (17.7%) and in 2019, when students were provided with time to participate in the survey during a teaching activity, the response rate reached 77.8%. Class sizes in those years ranged from 17 to 34 students.

Generally, over those years, all aspects covered in the unit survey questions are supported positively resulting in an average score of 5.3 on a scale of 1 to 6, where 6 represents “strongly agree” and 1 represents “strongly disagree”. Students agree to strongly agree that the unit provides clarity of learning objectives, appropriate assessment tasks and teaching activities, feedback, and staff support,

and are overall satisfied with the unit. Consistently over these years, students ranked most highly that assessment tasks were testing understanding rather than memory.

The comments section of the unit surveys provides further insight into student's judgement of the best aspects of the unit. In this context, the project was mentioned the most (followed by the laboratory activities). Aspects of the project that appealed to students included the exposure to a challenging, "real world", semester-long project that required them to synthesize and apply their prior knowledge and develop valuable skills for a practicing engineer. The application of industry standards, the integration and relevance of design approaches and lecture content taught in the unit and the development of teamwork skills were also considered as best aspects and linked to both project and laboratory activities. Some project-related responses to the survey question "Please tell us what you thought were the best aspects of this unit?" are:

"The main project. It was a real-world applicable exercise that was probably one of the most useful in my whole degree. It was also interesting, and the multi-phase structure allowed for clear definitions between the scope of each segment and allowed feedback and marks to be given while still working on the project." (2016 ENG421 Unit Survey).

"I feel the project is very close to a professional engineering job. It helps me understand what and how I should put efforts in my solar energy career in the future." (2016 ENG421 Unit Survey).

The unit delivery aspects that underpin successful project work were also recognized by students with positive comments on the feedback provided during the project stages, for example, "going through each of the design steps and getting constructive feedback along the way really helped" (2019 ENG442 Unit Survey).

In relation to the laboratory activities, students emphasized the usefulness of the reinforcement of concepts and the link to content covered in the unit, the exposure to a professional environment and facilities, the practical experiences and the hands-on and teamwork skills obtained. Example laboratory feedback responses include:

"The practical exercises . . . were the best aspects of this unit. After all the theory we have learnt over the years, these experiments really crystalized my knowledge of RAPS systems. These exercises have highlighted dangers and given me a lot of confidence in working with these types of systems in the future." (2013 ENG421 Unit Survey)

"Practical laboratories were engaging, well-structured and linked well to the unit content." (2019 ENG442 Unit Survey)

"Finally! I returned to University to complete units like this. . . . By far and away, the lab sessions were the best part of the unit and exposed the students to physical situations we will likely encounter in a professional environment, hopefully in the not-to-distant future!" (2013 ENG421 Unit Survey)

With its range of teaching and learning activities, the unit caters for a variety of learning styles. Even though project and laboratories were considered best aspects by most respondents, the site visit, guest lectures, lectures, and workshops were also listed by some.

Improvement suggestions provided through the unit survey comment section have been carefully reviewed each year. This regular review is firmly embedded in the reflective teaching practice in the Discipline of Engineering and Energy at MU and has led to several changes, which are regularly communicated to students. The changes are primarily associated with unit delivery, feedback, and assessment aspects. For example, students commented that they found the project helpful in their learning but criticized that the weighting of the assessment components did not suitably reflect the

effort required. Weighting has been adjusted to better reflect the effort required and the number of assessment items associated with the project has been reduced.

Weighting and workload of a laboratory report was criticized by students in earlier unit offerings. This assessment component has been replaced with presentation activities, which focus on key engineering reporting tasks and allow for timely feedback, thorough analysis, and class discussion of the laboratory exercise results facilitating comparisons of results from different groups.

There were few content specific suggestions with one respondent stating, "A bit more storage-focus in the entire degree would be nice." (2014 ENG421 Unit Survey) and another suggesting more emphasis on professional drawings, plans and schematics (2016 ENG421 Unit Survey). Both comments have been addressed in changes to recent unit offerings, where the project includes battery storage design elements as well as electrical design diagram requirements using software such as MS Visio or similar.

Group projects come with their challenges specifically when there are dysfunctional groups and groups with students of different caliber and background. Staff teaching the unit can spend a large amount of time facilitating group work and/or resolving disputes over contributions to project assessment items and ongoing review, application, and development of activities and practices to facilitate more effective group work as suggested by Barkley et al. [41] is required. Nevertheless, the high educational value of the project work as documented above justify these efforts, which need to be recognized as an integral and necessary part of engineering education.

A further challenge for renewable energy engineering units is reflected through respondent comments on the necessary upgrades to renewable energy laboratory facilities. As the industry is developing rapidly and standards for renewable energy system components and installations are changing, reviews to both content and facilities used in the unit are necessary and performed on a yearly basis. Keeping the educational renewable energy installations maintained and up to date is essential to and facilitates the attractive educational outcomes of the laboratory activities.

3.4.2. ENG442 Unit Calibration

The external peer review was conducted in early 2019 and the findings of the reviewer are summarized and discussed below:

- The unit learning objectives were found to be very well, clearly, and sufficiently presented in the unit information and very appropriate.
- The project was found to be a very suitable assessment task for the specified unit learning objectives and the reviewer emphasized the value of exposing students to a real case study, to a cost analysis and technical aspects of PV system installations. The project assessment requirements and marking criteria were found to be very appropriate, very well and clearly explained, and the reviewer judged that enough feedback was provided in the marking process. The reviewer agreed with all grades provided.
- Assessment task and marking criteria were regarded to be at Australian Universities standard and the unit was considered as well designed.

The key recommendations for improvements of the unit: "to provide further wind energy systems based material" and "introduction of other renewable energy based resources" seem to have been provided without the full insight of the reviewer into the curriculum of the REE major and the other assessment items in the unit, which cover wind energy systems-based material. The reviewer may also not have been that familiar with the content and tasks covered in the unit ENG339 Wind and Hydro Power Systems and with the other activities of the unit ENG442, as the materials that were provided for the calibration exercise were limited to those noted above. As the unit is already very demanding, and the project is essential for Clean Energy Council Accreditation requirements, there is little scope to add further wind energy material and/or assessments. The content of the unit, however, including the wind sections, is reviewed and updated each year with respect to relevance and currency.

The reviewer's feedback also initiated a laboratory and assessment development within the current unit structure, which is concerned with performance data analysis of small wind energy converters.

Currently MU does not have a formal procedure for academic calibration, in terms of 'closing the loop'. However, as part of this calibration exercise, the unit coordinator provided a feedback report on the unit review to the Head of Discipline and Academic Chair for noting and further discussions.

Overall, the calibration exercise provided very reassuring feedback on the adequacy of the unit's content, structure, and assessment items specifically related to solar energy systems. The review also endorsed the economic aspects of renewable energy systems, industry guest lectures, and industry-related content associated with the unit.

3.5. Outcomes of the MU REE Degree Major

Renewable Energy Engineering has been part of a suite of engineering courses accredited by Engineers Australia at MU. Meeting the accreditation requirements has been an ongoing and integral part of the REE course development since its inception in 1999. Provisional accreditation from Engineers Australia was originally granted for the Bachelor of Engineering in Renewable Energy Engineering, followed by full accreditation in 2004. Since then, the degree changed in structure with the current Bachelor of Engineering (Honors) and its major in Renewable Energy Engineering last accredited in 2014. MU's suite of engineering courses including the REE major will be reviewed for accreditation in mid-2020.

The Clean Energy Council (CEC) of Australia recognizes the successful completions of the units ENG337 Applied Photovoltaics, ENG339 Wind and Hydro Power Systems and ENG338 Energy Supply and Management of REE students as a pathway towards accreditation for stand-alone power system designers and the successful completion of the unit ENG442 as a pathway towards accreditation for grid connected PV system designers. Students who successfully complete these units (and their respective predecessor units) meet the provisional accreditation requirements of the respective accreditation types. MU and the University of NSW are currently the only universities in Australia to offer both these CEC accreditation pathways as part of an undergraduate engineering degree.

3.6. Future Directions of the MU REE Degree Major

MU is currently adjusting the structure of its Bachelor of Engineering (Honors) degrees and associated majors to create new learning options and improve sustainability of the courses. This initiative will continue to enable the current double major combinations (REE combined with Instrumentation and Control, Industrial Computer Systems, or Electrical Power Engineering) and additionally enable a double major with Environmental Engineering.

The upcoming Engineers Australia accreditation review of MU's undergraduate engineering degrees in mid-2020 will facilitate continuing industry engagement and benchmarking opportunities. Other benchmarking activities include a further unit calibration through the IRU process for the ENG337 Applied Photovoltaics, which is currently underway.

With the renewable energy industry rapidly transforming, REE specific units continue to require regular updates. These updates encompass unit content, laboratory developments, and replacements of laboratory and teaching facilities with renewable energy components and installations to enable student exposure to systems and equipment that meet current standards. To address these needs, the Discipline of Engineering and Energy at MU is currently engaging in several renewable energy training facility upgrades and laboratory developments associated with grid connected PV battery systems, lightning protection of system installations, virtual power plants, big data analytics, solar forecasting, and demonstrations of inverter requirements (power quality response modes). The discipline is also closely monitoring standard and best practice guideline developments, and any changes in the Clean Energy Council accreditation framework to align the REE curriculum with these developments.

MU recently announced a four-stage District Energy Project, which will see the installation of 5.7 megawatt of PV on existing buildings and a new car park at its main campus over the next few years.

This initiative aims to develop an educational and research facility with a variety of energy storage technologies and microgrid control options. The facility will be equipped with a sophisticated data acquisition system allowing for a multitude of educational and research activities, with operational and maintenance aspects of large PV installations being one of these. This living lab of renewable technologies on the MU Perth Campus will further support the educational activities within the REE and other engineering majors in future.

4. Discussion

4.1. Comparison of MU REE Degree Major with Teaching Pedagogies from the Literature

Meyers and Nulty [36] articulated five design principles that require third-year environmental students to learn about science through practicing the scientific method, and they specifically suggested that while their article illustrates the application of these principles in the area of science, the approach holds broad applicability across nearly all disciplines. Their five principles are therefore applicable to fourth-year renewable energy engineering students to learn about engineering through practicing the engineering design method. MU's approach in the REE major and capstone unit ENG442 closely follows this methodology. The design and delivery of ENG442 requires students to adopt a deep learning approach in order to meet the unit's assessment requirements, which in turn, meets the desired unit learning outcomes. To illustrate the application of Meyers and Nulty's [36] principles in ENG442, the group design project is based on a real customer (principal MN1) and the task requires them to develop an energy design for the town in a similar way as their future careers might require (principle MN1 and MN5). The laboratories are also designed to progressively give design exercises such that students develop their skills in, e.g., wind and solar assessment, system modelling (using industry-standard software), grid, and standalone inverter characteristics. These skills are directly relevant to their final design project (principle MN2, MN4, and MN5), which requires application of all these skills to the design of a system for a real customer (principle MN3).

As part of ENG442 (and other units), Murdoch faculty provide support and guidance throughout the students' journey through the group design project. This approach is aligned with the taxonomy of capstone engineering education discussed by Pembroke et al. [33] (principle Pem2, Pem4, and Pem5). As the students assign tasks to each other and may also take on formal roles within the group (such as leader, note taker, etc.) this provides practice in norms and expectations of professional work environments (principle Pem1), and the Murdoch faculty are assisting in this and may take on minor roles themselves (such as mentor) (principle Pem3).

The nature of the delivery and assignments of ENG442 where students work in groups to develop a detailed design for a real customer is also applying a problem-based learning pedagogical approach as described in Perrenet et al. [39]. The way in which laboratories and group work are worked on as a group, presented to the class, and then shared as a class discussion could be considered applying some of the principles of the collaborative teaching described by Barkley et al. [41], Byrne [52], and Hensley [42] such as jigsaw on a class basis. The working as a group, and then sharing with each other and then the class, helps to maximize learning and allows faculty to guide and support students as part of using this as scaffolding for the next topic and task. As the problem-based learning group work is interspaced with scaffolded and complementary laboratories and lectures in this way, this is also applying a balanced learning approach as discussed in Kandpal and Broman [8].

Student survey results for ENG442 mentioned their being provided with continual feedback throughout the unit as a significant positive. This aligns strongly with Hattie's [63] research where "feedback" and "providing formative evaluation" are both ranked within the top 20 out of 195 Influences on Student Achievement, with effect sizes of around 0.7 (when the average is around 0.4 and hence above 0.4 is considered significant). The way that the students present their project outcomes to the class at the end of the project and then participate in a class discussion of the learnings from all projects

aligns to “classroom discussion” and “reciprocal teaching”, which rank 10 and 14 and have effect sizes of 0.82 and 0.74, respectively.

There are several papers discussing the use of pedagogical approaches to teach sustainable development including within engineering courses and linking of specific pedagogical approaches that best align with specific sustainable development competencies. MU is already addressing all sustainability-related competencies from the Engineers Australia Stage 1 competencies within the REE major for the Murdoch REE course, as part of its achievement of accreditation with Engineers Australia. However, there may be scope to further align and expand pedagogical approaches with competencies for these subject areas (and beyond as described in Holgaard [48]) using published frameworks linking competencies with recommended pedagogies in sustainable development education such as Lozano et al. [49] as part of future course revisions.

4.2. Comparison of MU REE Degree Major with National Curriculum Frameworks

Comparing the recommended learning outcomes from the OLT study in Table 1 with the current learning outcomes of the third and fourth year REE specialization units (Tables 2 and 3, respectively) shows that the learning outcomes of the REE units, in general, align well with the recommended learning outcomes. This result is significant as the REE specialization units form a major within the BEng at Murdoch and are not part of a specialized degree on REE.

The combined learning outcomes from ENG337 and ENG442 go well beyond the recommended outcomes in Advanced RE Systems 1—Solar Photovoltaic and explore solar photovoltaics in greater depth. ENG441, however, is a single unit that covers both Solar Thermal and Biomass Engineering. Although it does not go to the same depth as the combined learning outcomes from Advanced RE Systems 2—Solar Thermal and Advanced RE Systems 4—Bioenergy, it gives an adequate presentation of these topics for a degree major. The learning outcomes of ENG338 do not match with any of the recommended advanced learning outcomes but align well with the recommended medium level learning outcomes of a unit referred to as Energy Efficiency and Management 1. ENG338 is focused mainly on energy management for buildings, including the sizing of solar and wind systems to supply the building’s energy demand. Groups of students conduct team energy audits on buildings, requiring communication and reporting skills that are valued by Engineers Australia. The learning outcomes of ENG339 match very closely to the recommended advanced learning outcomes for Advanced RE Systems 3—Wind Energy. There is only one recommended learning outcome that is not currently met by ENG339 and that is ‘be able to design the layout of a wind farm subject to environmental and social constraints’. Since the OLT curriculum framework is for a bachelor’s degree in sustainable energy engineering, there is more focus on the non-technical aspects of energy projects such as environmental, social, policy, and economic aspects. One clear difference is that ENG339 also covers the resource assessment, design, and implementation of hydro power systems. This may be broadly covered under the recommended medium level learning outcomes of a sustainable energy degree (under a unit referred to as Renewable Energy Systems 1) but ENG339 has a greater depth of knowledge in this area. Recommended learning outcomes in a unit entitled ‘Advanced RE Systems 5 – Remote and Micro-grid RE Systems’ align partially with learning outcomes of the unit ENG337 Applied Photovoltaics, which also introduces students to different types of PV, diesel, battery hybrid systems, their operation, associated standards and design aspects, and simulation of these systems. Murdoch is a leader in research in this area and incorporates a demonstration RAPS system in its teachings within ENG337, ENG339, and ENG442. As previously mentioned, completion of these units gives a student provisional accreditation with the Clean Energy Council for design of remote, stand-alone RE systems. Additionally, those students who are undertaking a double degree in REE and Electrical Power Engineering also study units on microgrids.

4.3. Comparison of MU REE Degree Major with Overseas Curriculum Frameworks

Comparing the MU REE specialization with emerging sustainable energy engineering undergraduate degrees around the world is difficult since each program differentiates itself by the range of energy courses that it has to offer. McPherson and Karney [12] try to compare four degrees from Universities in Canada; the Energy Program from the University of Toronto, the Sustainable and Renewable Energy Engineering Degree from Carleton University, the Electrical Energy System's Option from the University of British Columbia, and the Energy and Environment Specialization from the University of Calgary. Of these programs, Murdoch is similar to the Carleton degree in terms of energy subjects but not in structure as the Carleton degree is a four-year specialization. The Murdoch Engineering discipline is on a smaller scale than each of the four Canadian Universities, which had, in 2013, around 3000–4000 undergraduate engineers. The size of the engineering faculty plays an important role in the breadth of units and range of research projects on offer to the students. These limitations aside, MU would score reasonably well using the same multi-criteria evaluation framework developed by McPherson and Karney (see Table 4).

Table 4. Evaluation of the Murdoch REE specialization using the framework of McPherson and Karney.

| Category | Comment |
|---------------------------------------|---|
| Foundational Engineering Curriculum | Strongly present. Since most students enroll in a double major either with electrical engineering or instrumentation and control students are given a broad foundation in the first and second year in mathematics (calculus, linear algebra, and statistics), physics (mechanics and dynamics), programming, engineering economics, and electrical circuits. |
| Energy Subject Coverage | Strongly present. MU has a unit with content on Energy, Mass, and Flow and the topic of energy is also covered in units related to electrical engineering, and process engineering. The Toronto degree also covers nuclear energy but that is a broader energy degree. |
| Energy Sector Coverage | Mostly present. The REE specialization focusses on the electricity generation sector but the transport and building sectors are covered to some extent in the units on biomass (ENG441) and energy management (ENG338), respectively. The Toronto and Calgary degrees also cover the oil and gas sectors but again, they are broader energy degrees. |
| Sustainable Energy Coverage | Strongly present. The MU REE degree major has a focus on renewable energy technologies and students learn to assess technologies, e.g., hydro power, in terms of the sustainability of their operation. The sustainable use of energy is also covered in the unit ENG338 Energy Supply and Management. |
| Engineering Curriculum and Experience | Strongly present. The MU degree incorporates developing professional skills for preparing graduates for industry via Engineering Design Project, the Capstone Project (ENG442), and 450 hours of mandatory engineering professional practice. |
| Research Experience and Community | Strongly present. Compared to Canada, there is a smaller percentage of MU engineering graduates who go on to undertake higher degree research. However, the research experience is considered important to instill in the student skills of project management, independent thought, and report writing. The degree has an embedded Honors research project and this is mandatory for students undertaking the four-year engineering program. |

Overall, like the Canadian undergraduate programs, the MU REE specialization does not completely match the concept of a “complete modern renewable energy education” as proposed by Jennings [13]. The technical, resources, systems, and industry structure are well covered by the REE

specialization but there is an argument for additional content on the economic, policy, and social issues related to renewable energy projects. As McPherson and Karney [12] state, however, there is a limit of how many inter-disciplinary units that can be offered in an undergraduate engineering degree, without sacrificing some of the foundational engineering coursework that is required for accreditation of the course. Lund [54] suggests that the inter-disciplinary content is best reserved for further studies, via graduate certificates, diplomas, and Masters.

4.4. Comparison of MU REE Degree Major with Jobs and Industry

The current REE curriculum features technology specific units on solar photovoltaics, wind energy, hydropower, solar thermal, and biomass. The choice of these technologies in the curriculum as well as the focus on stand-alone (off-grid) PV design appears justified; the results of the International Renewable Energy Agency (IRENA) 2019 Annual Report on Renewable Energy and Jobs states, in 2018, [1]:

- The solar PV industry was the leading renewable energy employer and employed a third of the total workforce.
- Jobs in the biofuel industry increased up 6% to 2.1 million.
- The hydropower sector employed 2.1 million people, many of whom are in operations and maintenance, and is expanding slowly.
- The wind power industry supported 1.2 million jobs, mainly in the onshore segment but the offshore segment is starting to make up ground.
- There were rising numbers of jobs related to off-grid solar systems in order to provide energy access to isolated communities and promote economic activities.

The content of the MU REE degree major agree reasonably closely with the desired content from 60 industry stakeholders in Europe and Latin America as presented by Comodi et al. [11]. The required knowledge areas by industry in this survey were deemed to be Solar Energy, Wind Energy, Biomass, Biofuels, Grid Management Strategies (including Smart Grids), and Other. In both Europe and Latin America, around 30% of industry stated that solar energy should be the top priority in terms of field of expertise of graduates. There was a similar percentage (20%) in both continents in favor of biomass being the top priority. A key difference between the stakeholders in Europe and Latin America was that no European participants stated that wind energy should be a top priority compared to 20% of Latin American participants. Interestingly, the highest proportion of European industry in this survey mentioned that the top knowledge priority was Grid Management Strategies (35.7%). This reflects the maturity of the European market and the increased level of penetration of renewables in Europe, requiring knowledge and skills in optimizing emissions reductions and maintaining stability on a complex, dense, interconnected grid. Note also that the priorities of the Latin American companies may be more applicable for comparison with the MU undergraduate degree since only 12.5% of the European organizations were interested in employing graduates at a Bachelor level, compared to 38.5% of the Latin American companies. Finally, the content that industry deem as essential is location specific and depends on the availability of resources for a specific country of continent. MU have focused on remote area and microgrid power systems due to their applicability to Western Australia, although those REE students who are also studying an electrical power engineering will be familiar with management strategies for future electricity networks.

5. Conclusions

To address the research questions, a range of pedagogies have been identified that have been used in delivering sustainable energy units, courses, and degrees and other related educational areas. These approaches are predominantly based on providing students with practical knowledge and real-world experiences, using problem-based and group work pedagogies enhancing students' holistic professional preparation. This study has identified curriculum frameworks that can be used as part

of benchmarking sustainable energy engineering degrees, including a set of curriculum frameworks relevant to Australian sustainable energy education and an evaluation framework relevant to Canadian undergraduate energy engineering degrees.

Murdoch University's Renewable Energy Engineering degree major has been benchmarked against relevant teaching pedagogies from the literature, recommended curriculum from the Australian industry-aligned framework for an undergraduate sustainable energy engineering course, an evaluation framework from Canadian undergraduate sustainable energy courses, and content required from industry employers. The capstone unit of the degree major has also been calibrated via an Academic Calibration Program run by seven Australian Universities.

There are limitations to the study and to the extent to which the research questions have been addressed. The renewable energy industry is a rapidly changing industry and curricula and pedagogies need to be regularly reviewed. The set of Australian Government OLT curriculum frameworks were developed in 2015 and should be re-assessed in 2021. In addition, the number of undergraduates in the Canadian engineering programs exceeds those of Murdoch University and any comparison must take this into account. Finally, the results from the unit surveys of the capstone unit are limited by the number of students who choose to participate in the surveys.

The findings of this paper show that the pedagogical approaches used to teach the REE major at MU align with several pedagogical approaches used and recommended for other similar and relevant courses. For the REE major, there are strong similarities with published approaches used to teach renewable energy courses worldwide. There is also close alignment for MU's capstone unit (ENG442), which uses pedagogical approaches very similar to published approaches used by other universities to teach capstone units in both engineering and environmental majors as examples. The consistently positive feedback on the ENG442 unit from students reaffirms the success of the ENG442 unit and the approaches MU uses to teach it. The case study shows that MU's long-established history of teaching energy-related subjects, obtaining and utilizing frequent feedback from students on unit satisfaction and enjoyment, and other efforts such as unit calibrations, has contributed to its REE major being taught using established and internationally aligned pedagogical approaches.

A comparison with the Australian Government OLT recommended curriculum framework shows that the learning outcomes of the REE units, in general, align well with the recommended advanced learning outcomes for an undergraduate engineering degree in Renewable Energy Systems. Energy economics and grid-management are topics that should be considered in the next curriculum review of the major. The MU REE degree major curriculum would also score reasonably highly in the evaluation framework established from four Canadian universities that offer undergraduate sustainable energy engineering degrees.

The content of the MU REE degree major agrees reasonably closely with the desired content from 60 industry stakeholders in Europe and Latin America. Relevance to industry in Australia is demonstrated through accreditation by Engineers Australia and the fact that completion of the major gives graduates provisional accreditation for design of grid-connected photovoltaics as well as stand-alone (off-grid) power systems. With the renewable energy industry rapidly transforming, REE specific units and teaching facilities require regular reviews and the Discipline of Engineering and Energy at MU is currently engaging in several renewable energy training facility upgrades and laboratory developments. Part of the ongoing review and improvement of the REE major at MU is also the evaluation of a recent REE alumni survey regarding effectiveness and relevance of content and teaching methods. Future research will focus on the analysis of the survey results.

It is hoped that this benchmarking process will be of benefit to institutes developing or revising REE curricula, accreditation, and standards bodies and potential employers of renewable energy graduates as well as those interested more broadly in pedagogical approaches to sustainable energy education. In particular, institutes developing REE curricula may use similar methods to those used in this case study to contrast the curricula to that of recommended curriculum frameworks and to compare assessment and supporting materials to that of other relevant institutions.

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