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Sustainability, 2014; 6(7):4181-4199

Originally published at:
http://doi.org/10.3390/su6074181

Sustainability **2014**, *6*, 4181-4199; doi:10.3390/su6074181

OPEN ACCESS

sustainability

ISSN 2071-1050

www.mdpi.com/journal/sustainability

Article

A Peaking and Tailing Approach to Education and Curriculum Renewal for Sustainable Development

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Received: 24 March 2014; in revised form: 20 June 2014 / Accepted: 20 June 2014 / Published: 2 July 2014

Abstract: Contextual factors for sustainable development such as population growth, energy, and resource availability and consumption levels, food production yield, and growth in pollution, provide numerous complex and rapidly changing education and training requirements for a variety of professions including engineering. Furthermore, these requirements may not be clearly understood or expressed by designers, governments, professional bodies or the industry. Within this context, this paper focuses on one priority area for greening the economy through sustainable development—improving energy efficiency—and discusses the complexity of capacity building needs for professionals. The paper begins by acknowledging the historical evolution of sustainability considerations, and the complexity embedded in built environment solutions. The authors propose a dual-track approach to building capacity building, with a short-term focus on improvement (*i.e.*, making peaking challenges a priority for postgraduate education), and a long-term focus on transformational innovation (*i.e.*, making tailing challenges a priority for undergraduate education). A case study is provided, of Australian experiences over the last decade with regard to the topic area of energy efficiency. The authors conclude with reflections on implications for the approach.

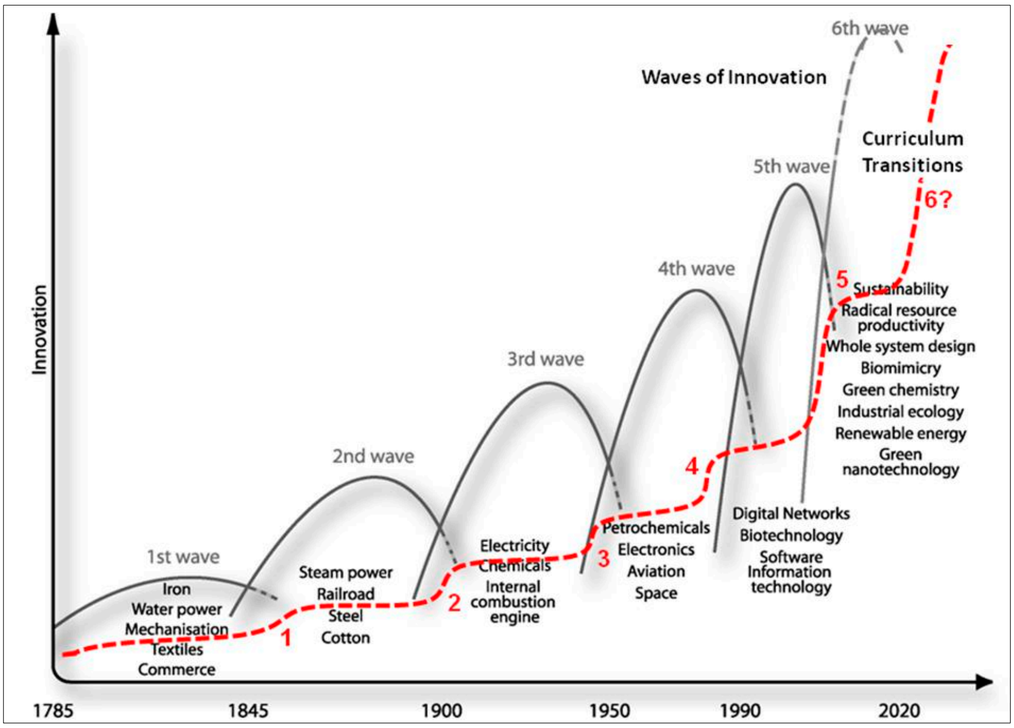
Keywords: sustainable development; capacity building; engineering education; built environment; energy efficiency; curriculum renewal

1. Introduction

Despite a decade of focus on education for sustainable Development [1], key professions in the built environment still lack critical knowledge and skills to bring about sustainable solutions. There is a plethora of literature on individual and institutional efforts to build capacity in delivering sustainable development and many discussions of drivers and barriers for doing so (see detailed review [2]). However, there is a relative absence of literature addressing a central dynamic in this challenge; namely how to systematically and rapidly equip decision-makers and professionals to carry out these recommended courses of action. In this paper the authors propose that this relative lack of progress is a result of many well-intentioned efforts that have been hampered by the complexity of the capacity building challenge and the momentum of current practices and approaches.

Consider that each of the waves of innovation shown in Figure 1 has brought about significant advances in technology over the last 300 years and has delivered a step change in the way industry and society have operated. The waves of innovation model [3] builds on the foundation of Kondratiev's wave, extending the theory to consider a sixth wave of innovation that addresses sustainability considerations. In Figure 1, we overlay an illustrative schematic of capacity building activity, highlighting the contribution of education to equipping society with knowledge and skills to mainstream the innovations.

Figure 1. A schematic of curriculum renewal transitions resulting from significant waves of innovation since the Industrial revolution.



Source: Desha and Hargroves [4] (Figure 1), adapted from Hargroves, and Smith [3] (p. 17, Figure 1.1).

Despite the precedent and need for up-skilling alongside innovation, generally speaking there is a low level of understanding regarding the importance of building capacity to support the sixth wave of innovation. Not only are references to capacity building towards the end of reports on requirements for action, they are cursory and high-level, referring to the need for vocational and specialist training, awareness raising in the community and assistance with building and supporting professional communities of practice to deliver such solutions. There are a range of propositions as to why this is the case, including "lock-in" theory [5], which suggests our current ways are too well adjusted to the presence of fossil fuels, resulting in limited ability to "think laterally" about problem-solving or alternative options.

Drawing upon this historical context, this paper proposes a strategic approach to capacity building that focuses on the topic of energy and addresses both short and long-term capacity building needs. The paper begins by acknowledging complexity embedded in developing sustainable solutions, and the need for capacity building for energy efficiency. We then discuss the opportunity for strategically undertaking a dual-track approach to curriculum renewal in undergraduate and postgraduate education, to address peaking and tailing needs. We reflect on what has transpired over the last decade in Australia with regard to vocational and higher education efforts to build capacity, distilling a number of insights that can inform such an approach. We conclude with recommendations for further action in the field, to create strength in professionals to contribute to greening the economy.

2. Evolution of Capacity Building for Sustainable Development

A key challenge for the education sector in the 21st Century will be to provide society with professionals in a meaningful timeframe, who can respond to significant threats such as climate change in a way that continues to strengthen economic development [6]. This requires accelerating education renewal efforts in a relative absence of precedents for such acceleration. In this section, we consider the evolving nature of education for sustainability and discuss the complexity of building capability, to gain insight into opportunities for accelerating capacity building efforts.

2.1. A Historical Example of Engineering Education

In *Higher Education and Sustainable Development* [2] a commentary is provided on the journey of engineering education from the Industrial Revolution to the present, as an example of how a profession gradually evolved to include environmental education in practice and associated training. Summarizing this journey, a number of phases of activity are highlighted here:

- *Environmental Acknowledgement*: At the time of the Industrial Revolution, primary concern involved applying science fundamentals to engineering design such as the mechanics of motion and combustion), and in increasing process productivity. In this way, outcomes were influenced by environmental considerations to the extent of energy and resource considerations, and physical constraints.
- *Ad hoc Environmental Education*: In the mid to latter half of the twentieth century, an increasing but *ad hoc* environmental influence stemmed from concerns that some design outcomes could adversely affect the environment (for example with air and water pollution), following the release of seminal publications, such as Silent Spring [7], Limits to Growth [8], and Our Common Future [9], and events, such as the Bhopal chemical disaster in 1984, and the nuclear accident in Chernobyl in 1986. Content was included within existing programmes, often based on interests and pursuits of individuals as educators realized the need to address such issues.

- *Flagship Environmental and Sustainability Education*: From the 1980s, educators began to formalize *ad hoc* activities, responding to increasing interest in the way engineering affects the environment. However, environmental considerations were still isolated and sparse within the average curriculum. Furthermore, "Environmental Engineering"—and more recently "Sustainable Engineering"—emerged where many identified "environmental" or "sustainability" issues' could be addressed without affecting the curriculum of other disciplines.
- *Integrated Education towards Sustainable Development*: Within the last decade or so, a more holistic form of education is taking shape, in the form of education for sustainable development. A growing number of institutions internationally are proactively integrating sustainability considerations into all curriculum as appropriate, to address shifting regulatory, market, institutional, and graduate expectations.

Unfortunately, despite these shifts in focus, education—particularly higher education—is still teaching curriculum focused on 20th Century-related knowledge and skills. Various researchers have written about the challenges and opportunities in this state of affairs. See, for example, Holmberg and Samuelsson [10] who documented higher education issues, the United Nations Educational Scientific and Cultural Organization (UNESCO) report on engineering globally [11], Allenby *et al*. [12] who describe efforts in engineering education in the United States, and Byrne *et al*. [13] who describe engineering education efforts in Europe.

An overarching challenge with this lack of progress becomes visible in looking forward towards timeframes for transitioning curriculum to embed sustainability-related knowledge and skills [14]. As a typical process of undergraduate curriculum renewal could take three to four accreditation cycles of approximately five-year intervals, with the resultant timeframe for fully integrating a substantial new set of knowledge and skills within all year levels of a degree in the order of 15–20 years. Considering that a student may take four to five years to graduate, then experience three to five years of graduate development, a business-as-usual approach to curriculum renewal could result in a time lag of some two to three decades before students graduating from fully integrated programs will be in decision-making positions. For postgraduates who may already be practicing in their field, and who can immediately apply their acquired knowledge and skills, the time lag could still be in the order of 8–12 years, depending on the pace and effectiveness of curriculum renewal efforts.

2.2. Addressing Energy as a Priority for Capacity Building

Many parts of the world currently experience wealth and prosperity that is unprecedented in scale and composition, a phenomenon well referenced in the literature, including for example the latest Intergovernmental Panel on Climate Change report [15]. Much of this prosperity is founded on one or more of the series of innovations shown in Figure 1, beginning in the mid 1700s with the Industrial Revolution, spanning industrialisation, mechanisation, electrification, and digitisation. However it is also the case that many of these innovations have had varying levels of associated environmental pollution—of the earth, water and air. Indeed, there are many examples of such pollution impacting on quality of life, and which are now resulting in "*environmentally induced economic decline*" [16–18]. Arguably the most significant global pollutants are greenhouse gases, which are already influencing climatic conditions to the detriment of food production, urban livability and infrastructure provision [15].

Alongside this challenge of addressing existing "legacy" pollution, one of the most pressing current—and future—challenges for the human species is to meet growing energy demands of a population that is also itself still increasing [18,19]. With rapid expansion in demand for such things as white goods, electronics, processed food, international travel and the latest fashion items, it is concluded by most that our previous pattern of fuel composition—including using fossil fuel as the predominant fuel source of this energy—will not suffice into the future (see for example Godfray *et al.* [20], and Vörösmarty *et al.* [21]). Not only are fossil fuel reserves diminishing and increasing in cost of extraction, but the combustion of these fuel sources contribute further to atmospheric greenhouse gas pollution, and substantial disruption and changes to global climate.

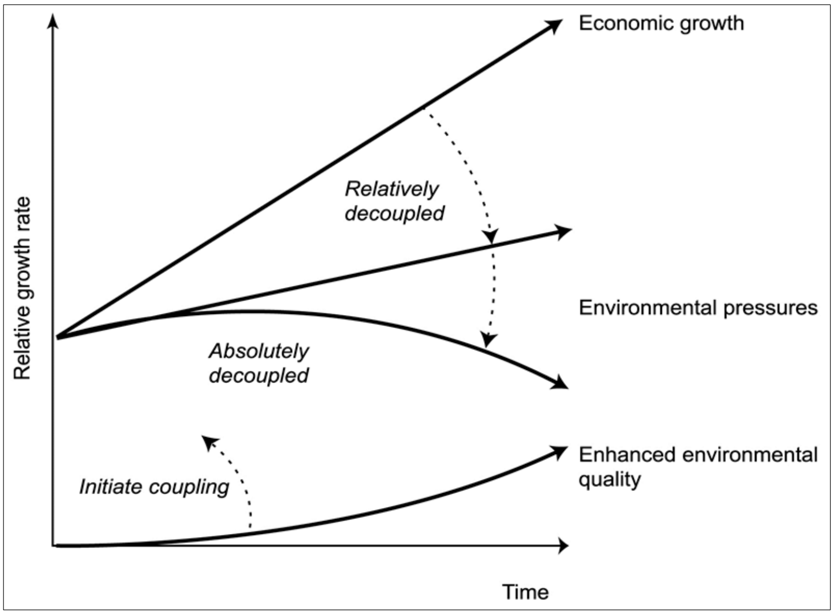
In considering the scale of existing atmospheric pollution and the need to avoid adding to this pollution, there is a plethora of literature on the need to urgently and substantially reduce fossil fuel combustion as an action requiring global prioritization (referenced in Stern [16] and Stocker [15]). Numerous authors within this literature have also documented how this is possible, considering planning and regulatory requirements, and drawing largely on existing technology. Indeed there is the potential for energy demand reductions of 60 to 80 percent, with little impact on lifestyles [22]. Such reductions in demand then make renewable energy much more manageable as a significant component of supply, particularly when coupled with battery storage. In summary, fossil fuel use can be reduced significantly and quickly through two main avenues, namely improving energy efficiency and energy demand management practices where fossil fuel is used as an energy source, and switching to non-fossil energy sources, such as renewable energy options.

2.3. Decoupling as a Construct for Dual-Track Curriculum Renewal

The concept of "decoupling"—separating the rate of economic growth from the rate of negative environmental pressure [23]—provides a useful construct for considering the changing nature of capacity building needs in the built environment sector. As shown in Figure 2, the increasing growth of environmental impacts, or pressures, first needs to be slowed compared to the growth in economic performance, achieving what is referred to as "relative decoupling". For instance as outlined in von Weizsäcker *et al.* [22], the growth of CO_2 emissions can be significantly reduced through fuel switching, process innovation, energy efficiency and demand management, and cogeneration, while continuing to deliver economic growth. Once this is achieved the goal is then to "peak" the growth of the environmental pressures (meaning to halt any increase in the growth rate) and then reduce the growth rate of the pressures relative to the economic growth over time to achieve what is referred to as "absolute decoupling". The goal of absolute decoupling is to reduce the associated environmental pressure from the generation of economic growth to such a low level that it can either be offset by activities in other areas of the economy or is within the capacity of receiving environments.

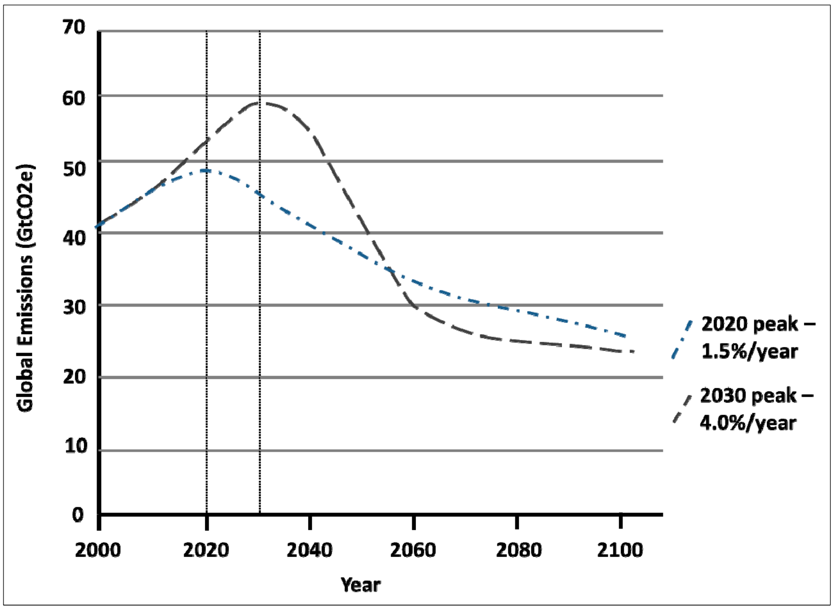
Such a decoupling agenda, applied to the greenhouse gas mitigation challenge, provides a complex challenge for education and skills development. Absolutely decoupling greenhouse gas emissions involves many actions to halt the relative growth of greenhouse gasses emitted (*i.e.*, peaking) in the short-term, and then to reduce the growth in emissions over time to reach the long-term target (*i.e.*, tailing). As shown in Figure 3, the timing of the peak will have a significant impact on the requirement for tailing to achieve greenhouse gas emissions target levels. In this case the target of 550 ppm CO_{2e} can be achieved with through an early peak around 2020 followed by a tailing of 1.5% per year, or through a late peak around 2030 that would then require a tailing of 4% per year, which would be challenging for economics to achieve. Considering such scenarios, Stern [16] concludes, "*Given that it is likely to be difficult to reduce emissions faster than around 3% per year, this emphasises the importance of urgent action now to slow the growth of global emissions, and therefore lower the peak.*"

Figure 2. Illustration of peaking and tailing dynamics in decoupling economic growth from negative environmental pressure.



Source: Smith *et al*. [23] (p. 32, Figure 2.2).

Figure 3. Illustration of two peaking and tailing trajectories to achieve 550 ppm CO_2.



Source: Desha and Hargroves [4] (p. 17, Figure 1.4), adapted from Stern [16] (p. 226, Figure 8.2).

As explained by Desha, Hargroves, and Reeve [24], the dual-track nature of the decoupling agenda will have a strong influence on education and skills development to both deliver the peak and the ongoing reductions as part of the tailing. The authors reflect:

> *Such peaking and tailing scenarios can involve different short and long-term strategies. For example, under the shorter term peaking scenario, capacity building needs to focus on identifying the knowledge and skills required to respond to energy [saving] opportunities, such as undertaking energy efficiency audits, installing solar hot water and energy systems, and understanding the energy performance and retrofitting opportunities for domestic appliances and industry equipment. Implementation might involve "just-in-time" style postgraduate education such as certificates, diplomas and masters programs, alongside professional development seminars and short courses. In the longer term, a sustained reduction in greenhouse gas emissions will involve further energy [saving] improvements, as well as a large scale transition to low-emissions energy sources, such as solar, wind, geothermal and tidal power. This would require capacity building at the undergraduate level, with a focus on areas such as whole-system design, resource productivity and transformational improvements.*

Within this context, the complexity of educational needs for professionals delivering solutions towards these end goals becomes apparent. Returning to our earlier discussion of timeframes, as the majority of engineering and built environment higher education programs have yet to embed sustainable development related knowledge and skills this process is likely to take 8–10 years, at least two accreditation cycles. Then when adding the 4 years for the first cohort graduate, and another three to five years of work experience before they can meaningfully contribute to projects, it is likely to be at least 20 years before graduates are equipped on mass to contribute to greenhouse gas mitigation, which puts them past the 2030 "late peak" example in Figure 3. Given that they will miss the period of time when peaking is priority, undergraduate curriculum renewal should focus on preparing undergraduates to contribute to the tailing of greenhouse gas emissions. This is of course assuming that post graduate programs quickly gear up to support graduates and practitioners to contribute to the peaking as these students are already in positions of authority and able to effect change. Figure 4 illustrates the varying dynamic in curriculum renewal efforts between undergraduate programs and postgraduate programs (including diplomas, masters and vocational education, and training), to cater for these differing timeframes and knowledge and skill needs.

With this in mind, short-term peaking needs are therefore most likely to be met through equipping current practitioners with new knowledge and skills to immediately put into practice. In contrast, medium and longer term tailing needs are most likely to be met during the career timeframes of current and future undergraduate students. These implications are summarized in Table 1.

Figure 4. Illustration of a Dual-Track Approach to Education Renewal for the Green Economy.

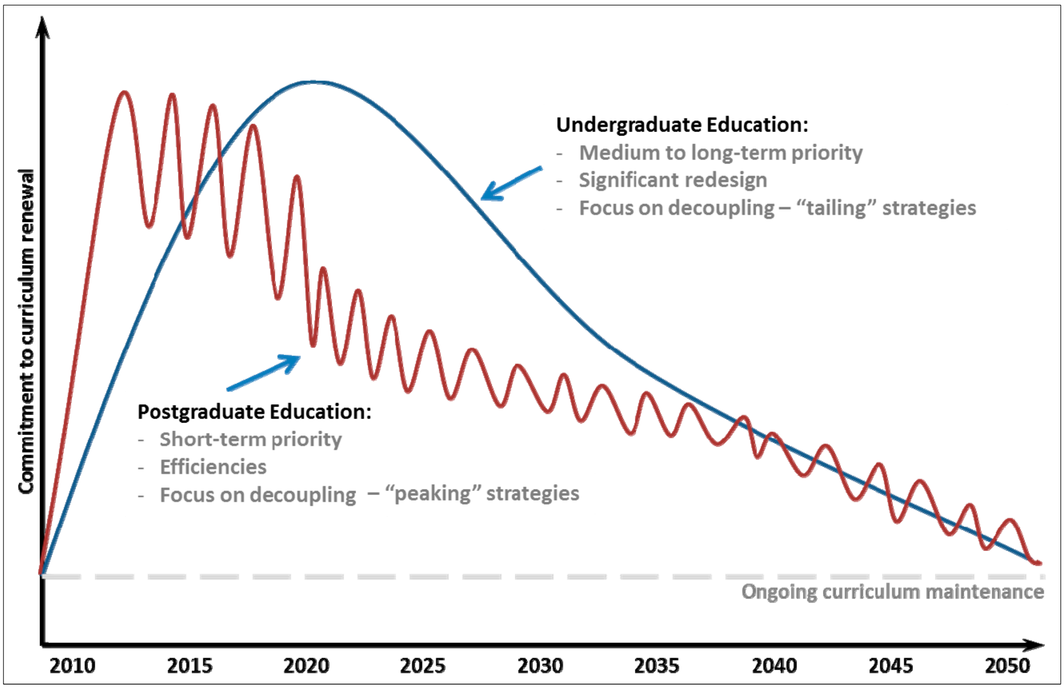


Table 1. Implications for building capability towards sustainable development, at undergraduate, and postgraduate levels.

Curriculum renewal priorities	Undergraduate Implications	Postgraduate Implications
Deliberative and Dynamic Curriculum Renewal Model (Desha and Hargroves 2014): • Creation of curriculum renewal strategy • Identification of preferred graduate attributes • Mapping of learning pathways for attributes in existing programs • Auditing current levels of coverage of attributes • Development and updating of new materials • Trialing and implementing new materials • Revision of preferred graduate attributes	**Short term:** • A focus on common first year courses and final year capstone projects • Trialing inclusion of case studies and worked examples across various units • Capacity building opportunities for staff interested in area	**Short term:** • A Focus on intensive courses linked to industry practice • Trialing targeted training to support specific "low-hanging" fruit opportunities • Incorporating real time expert advice to enhance operational aspects
	Medium term: • A focus on a specific program to appropriately embed new curriculum across year levels (incorporating postgraduate content where appropriate)	**Medium term:** • A focus on expanding intensive courses into postgraduate programs to deliver ongoing professional development programs
	Long term: • Expand curriculum renewal to all programs with ongoing curriculum renewal maintenance	**Long term:** • Ongoing curriculum renewal maintenance

Within this context, over the last decade the authors of this paper have undertaken a range of action research projects on building capacity in Australia, with the aim of improving energy outcomes through increasing productivity and reducing energy demand. This journey has been one of opportunistic research following different sectors and research questions as grants were made available, and strategic in building a rigorous understanding of the problem before attempting interventions within the education sector. The research has also been informed by the first author's PhD enquiry into rapid curriculum renewal, spanning curriculum renewal theory and engineering education. During this period of grounded research inquiry, the authors gained a number of insights into challenges in the type of systemic curriculum renewal that is required to build capacity for problem solving, in particular in the complex topic of energy efficiency. In the following section the authors' Australian experiences are discussed with respect to addressing the dual-track approach to curriculum renewal for energy efficiency solutions. Three over-arching themes are then used to present key insights, including "knowledge and skills", "pedagogy considerations", and "strategic support".

3. An Australian Case Study in Energy Efficiency Capacity Building

Modelling by the Commonwealth Scientific and Industrial Research Organization (CSIRO) shows that approximately three million Australians will need training or re-training in topic areas such as energy efficiency, green building technologies, sustainable energy and more sustainable agricultural systems to achieve the Intergovernmental Panel on Climate Change's (IPCC) recommended minimum reductions [25], and recent studies by the Federal Government (Department of Resources, Energy and Tourism, [26]) show that, in Australia there are still few higher education institutions embedding energy efficiency within their professional engineering degrees, resulting in a missed opportunity for 6000 or so Australian engineering graduates finding work domestically or overseas each year. The Council of Australian Governments (COAG) acknowledge energy efficiency initiatives as a relatively straightforward and cost effective way to reduce rising greenhouse gas emissions and manage rising energy costs [27,28]. Contributing professionals in this context include undergraduate and postgraduate students, and professionals undertaking continual professional development in the workforce [29]. This is recognised by the Institution of Engineers Australia in its policy on climate change and energy, which states that, "*Engineers Australia believes that Australia must act swiftly and proactively in line with global expectations to address climate change as an economic, social and environmental risk*" [30].

Reflecting on initiatives relating to energy demand and supply, formal efforts in capacity building for energy efficiency span at least a decade. Over this period a team of researchers (*i.e.*, The Natural Edge Project research group) engaged with mentors and colleagues in the fields of sustainable development and education research to create a series of peer reviewed textbooks and online lectures that introduce key principles and practices related to sustainable development [31]. Once completed the team then focused on researching challenges and opportunities within a sub-topic area of sustainability, that of "energy efficiency", which allowed for specific research to be undertaken as summarized in Table 2. In the following paragraphs key findings are distilled from these action research projects that have contributed to better understanding short and long term needs—of academics, industry, and students—and situate these findings in the literature on education for sustainability. Where there are published details findings for individual projects, these are noted within the table.

Table 2. An example of education for sustainability research, in energy efficiency in Australia (adapted from Desha and Hargroves [2] (pp. 38–39, Table 2.8)).

Year	Research Summary (Funding Provider and Aim)	Key Research Findings
2007	National Framework for Energy Efficiency (NFEE). *Survey of energy efficiency education across all Australian universities teaching engineering (undergraduate and postgraduate), with 82% participation rate* [32,33]	The state of engineering education is *ad hoc*, champion based and highly variable. Lectures reluctant to engage in professional development, and want stand-alone resources easily embedded within existing curriculum.
2007	CSIRO. *30 lecturers on energy efficiency opportunities in Australia, by major sector and technology, as part of the "Energy Transformed" Flagship Program* [34]	Across the major sectors of the Australian economy, there exist a myriad of existing technologies and precedents for using these to achieve significant improvements in energy performance.
2009	NFEE. *An exploration of barriers and benefits to teaching energy efficiency in the higher education sector, particularly focusing on engineering education* [35]	A number of common and specific barriers and opportunities exist to integrating energy efficiency knowledge and skills in engineering.
2010	NFEE. *Research report to examine "energy efficiency assessment skills" in Australian Industry, called the Long Term Training Strategy for the Development of Energy Efficiency Assessment Skills* (LTTS) [36]	Analysis of energy use data comprised the greatest unmet demand for skills in understanding energy use, namely: Identifying potential opportunities; Evaluating costs and benefits for inclusion into business cases; and Technical calculations required to develop energy mass balances
2011	Federal Department of Resources, Energy and Tourism (RET). *National Energy Efficiency Advisory Group defined 2 projects (led by the authors): (1) update of 2007 NFEE survey and taxonomy for energy efficiency education resource development* [37]; (*2) graduate attributes and associated learning pathways relating to energy efficiency* [38]	The state of engineering education has shifted in some areas, but by and large still *ad hoc,* highly variable and champion driven. Lecturers have clear desires for support in the form of ready-to-use targeted resources and clear preferences for their composition and delivery.
2011	NFEE. *Investigation into postgraduate education for energy efficiency, including consideration of connectivity with the vocational education sector* [39]	Postgraduate education suffers from a fragmented and reactionary approach to curriculum development, with little connectivity.
2011	New South Wales Office of Environment and Heritage/ Department of Education and Communities. *(Within the "Energy Efficiency Training Program") for two universities to create targeted coursework on energy efficiency priority topic areas* [40]	Industry relevant coursework on energy efficiency benefits significantly from close collaboration with industry and experts in the field, to ensure the content is contextual and pushes the boundaries in innovation.

Table 2. *Cont.*

Year	Research Summary (Funding Provider and Aim)	Key Research Findings
2012	RET. *Consultation with industry and academia on targeted capacity building for energy efficiency, in collaboration with Engineers Australia, through nine national engineering colleges and discipline based groups* [26]	Key findings from the workshops and focus groups were used to prepare a Consultation Report and Briefing Paper on energy efficiency assessment education opportunities by core engineering discipline
2013	Federal Department of industry, Innovation, Science, Research and Tertiary Education (DIISRTE). *Assessment of the state of energy efficiency in vocational education programs in Australa under the "Skills for the Carbon Challenge" initiative* [41]	While the majority of respondents (80%) indicated that they felt personally motivated and inspired to teach about energy efficiency, less than half of the respondents indicated that the qualification/course they were involved in teaching currently had a unit of competency with a primary focus on energy efficiency.
2013–2014	Federal Department of Industry. *Program to develop open-source, online resources for engineering education on the topic of energy efficiency assessments.* [42]	Critical factors include: the importance of exploring stakeholder needs in detail before attempting curriculum renewal; the benefits of pooling ideas and faculty to create projects viable for federal funding, contractual challenges in engaging multiple universities to jointly develop curriculum resources over short timeframes.

3.1. Insights into Energy Efficiency Knowledge and Skills

The literature contains numerous papers by individual academics discussing what sustainability knowledge and skills should or should not be included within higher education curriculum. For example see Karatzoglou [43] who overviews evolving roles and contributions of universities to education for sustainability, Barth *et al.* [44] and Wiek *et al.* [45] with regard to key competencies, and Ashford [46] and Allenby *et al.* [12] who consider American engineering curriculum. Such discussions include a mixture of literature on technical and non-technical knowledge and skills, often in no particular arrangement. There are few conversations in the literature with regard to the characteristics of sustainability knowledge and skills in higher education curriculum versus vocational education and training. Notable exceptions include two Australian authors Tilbury [47] and Sibbel [48], who mention differences in their discussion of pathways for universities to contribute to sustainable development.

Considering the experiences highlighted in Table 2, and three key insights are noted with respect to the type of knowledge and skills related to energy efficiency education:

- *A suite of priority (short term) knowledge and skill needs:* Tracking knowledge and skill needs from 2007, it is clear that needs have evolved from general principles about context (*i.e.*, including greenhouse gas emissions, climate change, and alternative energy options) to become more targeted in recent years. In the last two years in particular, academics have clearly articulated graduate attribute statements and learning outcomes relating to "identifying", "evaluating" and "implementing" energy efficiency assessments, and industry has clearly called graduates who are skilled in "whole system thinking", the ability to "communicate", and the ability to "develop a business case" about energy efficiency improvement options [42].
- *A spectrum of knowledge and skill requirements spanning vocational and higher education*: Early efforts were directed largely at vocational education, in particular with regard to energy efficiency assessments, product installation and maintenance of existing systems. It has only been in the last few years that higher order learning needs have been acknowledged within the energy efficiency field, by professional bodies, such as Engineers Australia, professional associations, such as the Australian Sustainable Built Environment Council, Australian Power Institute, Energy Efficiency Council, and Mining Education Australia. This diversity of training needs to be accommodated in short and long-term strategic planning for capacity building.
- *A range of technical and enabling knowledge and skill needs:* Over the last decade, the need for both technical competencies (*i.e.*, such as calculating greenhouse gas emissions) and enabling competencies (*i.e.*, such as the ability to communicate with financial officers) has become widely articulated, particularly through the more recent long-term training strategy report [36] and subsequent national consultation [26]. Such knowledge and skills at post-graduate levels will help address short term needs for robust audits of energy efficiency opportunities, while embedding such knowledge and skills within undergraduate education will equip students with a changed view of what is possible with regard to future design, operation, and maintenance of infrastructure.

3.2. Insights into Pedagogy Priorities for Energy Efficiency Education

Education for Sustainability literature contains many references to individual and institutional attempts to embed sustainability knowledge and skills into their curriculum through learning and teaching innovation. This includes for example Lehmann *et al.* [49] with regard to problem-oriented education, and Quist *et al.* [50] with regard to back-casting. However, as noted by Segalas *et al.* [51], pedagogical innovations have the potential to make or break student engagement with any topic area. Indeed, the most complicated concept can be made exciting through careful consideration of the way in which the theory and application are delivered.

Considering the projects summarized in Table 2, three insights are noted in relation to energy efficiency education, which could assist in future curriculum renewal efforts:

- *Time-poor and curriculum-savvy education providers:* In the development of freely available online resources, the focus should be on flexible materials that education providers can splice and insert into existing curriculum as they see fit. Efforts that overlay prescriptive directions about *how* knowledge and skills should be taught on top of *what* should be taught, are restrictive and not highly regarded.
- *Flexible, autonomous, and endorsed resources:* Further to the above point, education providers are keen to have access to flexibly designed resources that can be quickly manipulated into a range of delivery formats (e.g., lecture slides, tutorial notes, home reading, webinar material, audio-visual provocation).
- *A time and place for future-flexible and temporal resources:* Depending on the knowledge and skill area being developed, the resource may need to be created for short, medium or long-term application. Where the goal is for long-term use, references to contextual examples, *etc.*, that date need to be avoided. On the flipside, resources for short-term use need to include as much context as possible, engaging with industry, professional bodies, and associations to target priority needs.

3.3. Insights into Strategic Support for Energy Efficiency Education

There is a growing volume of literature on curriculum renewal from the perspective of behavior change and organizational change theories, highlighting the importance of institutional transitions to sustainable entities including their operations and teaching networking and collaborative resource development. For example, the authors' own "Helix" for organizationally supported rapid curriculum renewal [2], and ECOS articles [52,53], Sterling [54] who proposes a framework for teaching and learning for sustainability in the UK, Briggs [55] who considers the role of collaboration, Counce [56] who considers industry and government perspectives, and Barth and Rieckmann [57] who consider academic staff support to catalyse curriculum change.

Considering the projects summarized in Table 2, a number of organisations have been engaged through consultation, as a funding partner over the last decade, including for example the National Framework for Energy Efficiency, and the Energy Efficiency Advisory group. Such interaction has helped to create a robust set of knowledge and skill attributes and learning outcomes for energy efficiency education.

Four key insights are noted here, relating to providing strategic support for energy efficiency education, which could assist in future curriculum renewal efforts:

- *Institutional focus on developing its own priority graduate attributes:* Curriculum renewal was relatively straightforward in those projects where there was a clear understanding of gaps and strengths in the departments who were going to manage the integration of energy efficiency knowledge and skills. For example, finding areas of importance *and* low-level current coverage.
- *Timely and strategic use of school/departmental/other funding, to create time to undertake systematic curriculum renewal:* As the topic of building capacity gains momentum and interest, it is important for funds to be made available and in a timely manner, to remove this barrier to staff participation in curriculum renewal.
- *Strategic use of collaborative projects with other institutions to develop resources (funded):* Joining forces with colleagues from other institutions can provide a time and budget saving opportunity to create shared resources. However, government and university structures do make contracting difficult—the tabled projects have almost all been logistically challenging to undertake even though they have had so many benefits.
- *Low regard for professional development, but high regard for professional institutions:* In particular, educators are prepared to use open source resources if they can be readily incorporated (*i.e.*, logistically regarding file size, copy-pasting, formatting, in addition to not having to acknowledge a competing institution.

4. Conclusions

In a world with such variety in supply and demand, infrastructure and governance, the potential for large-scale change in energy use is a complex challenge, requiring expertise and proficiency in knowledge and skill areas previously unknown. Indeed, the early part of the 21st century is an era of major transition, and an era requiring strategic thinking to build capacity across all levels.

Acknowledging the relative absence of literature discussing this complexity, or potential ways to address the challenges presented, in this paper the authors considered opportunities for innovation in curriculum renewal, drawing on experiences in Australia with the topic of energy efficiency education. In particular, the authors discussed the potential for a dual-track approach that focuses postgraduate education on short term peaking of greenhouse gas emissions in the current decade, and undergraduate education on medium to long-term gradual tailing of emissions over the coming two to three decades. The referenced literature and Australian journey with regard to energy efficiency in engineering education highlight the characteristics of such a whole of system approach to capacity building for such proficiency in the workforce this century.

It is concluded from the insights discussed, that greater effort be made to investigate, document and support the design of curriculum renewal strategies aimed at sustainable development. It is important in this process that industry is included to provide a quality assurance check on proposed priority graduate attributes. Regardless of the time-horizon for capacity building efforts, sharing knowledge critical, to go beyond individual *ad hoc* approaches which are quite vulnerable to institutional change. Within the context of the Australian journey, the discussed projects have been able to demonstrate the potential for autonomous, online and freely available resources to address high priority, critical energy efficiency related knowledge and skill gaps identified by industry and Engineers Australia college representatives. The next challenge will include leveraging support for such outputs into further funding for more educational resources on other critical topic areas, addressing short *and* long-term educational needs.

Acknowledgments

The authors would like to acknowledge the hundreds of academic, industry and government colleagues in Australia and internationally who have shared their experiences and insights regarding capacity building for sustainable development over the last decade. Such opportunities to ground-truth concepts and models have steered the inquiry towards pragmatic and useful tools for accelerating efforts towards education for sustainable development.

Author Contributions

The authors listed both contributed to the development of the theory and discussion contained within this paper, building on previous works as noted within the text. The paper's structure, case-study and revisions were led by the first author.

List of acronyms

COAG	Council of Australian Governments
CSIRO	Commonwealth Scientific and Industrial Research Organization
IPCC	Intergovernmental Panel on Climate Change
NFEE	National Framework for Energy Efficiency
NSW	New South Wales
OEH	Office of Environment and Heritage
PD	Professional Development
PG	Postgraduate
RET	Federal Department of Resources, Energy and Tourism
UG	Undergraduate
UNESCO	United Nations Educational Scientific and Cultural Organization

Conflicts of Interest

The authors declare no conflict of interest.

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