2026 ASEE ANNUAL CONFERENCE June 21–24, 2026 | Charlotte Convention Center, NC
Host Sponsor UNC Charlotte
Paper ID #51047

Sustainability and Sociotechnical Thinking: A Narrative Literature Review

Mikayla Friday, University of Connecticut

Mikayla is a third-year PhD student studying Engineering Education at the University of Connecticut. She received her bachelor's in Environmental Engineering from the University of South Florida. Her interests include sociotechnical thinking, sustainability education, and energy systems.

Desen Sevi Özkan, University of Connecticut

Desen is an assistant professor at the University of Connecticut in the Chemical and Biomolecular Engineering Department. She holds a Ph.D. in Engineering Education from Virginia Tech. Her research focuses on sociotechnical engineering education and how people make sense of complex sociotechnical energy infrastructure and systems.

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Abstract:

Sustainability is an important goal across disciplines within the university and within society, but its definition often varies greatly. This is not necessarily a bad thing—there is not an agreed-upon definition of sustainability, and it has been argued that a universal definition of the term does not make sense, due to its deeply contextual nature (Ramsey, 2015). In the context of engineering education, the definition and operationalization of sustainability is often reduced to quantifiable domains, which aligns with engineers' traditionally accepted roles in society (Allenby et al., 2009). Two relevant literature reviews (a scoping and a systematic review, respectively) have been conducted to assess the landscape of sustainability within engineering education (Gutierrez-Bucheli et al., 2022; Sundman et al., 2025). Both found that experiential and project-based learning are common approaches to this initiative. However, each review also found that these attempts at integration often come up short, lacking broad interdisciplinarity or failing to inspire deep and transformative learning within students.

A key piece that may help produce transformative learning in students and a deeper understanding of sustainability beyond that which is quantifiable is an integration of sociotechnical systems within the engineering classroom. This paper reviews three sociotechnical lenses that can be used to strengthen sustainability engineering education: the social construction of technology (Pinch and Bijker, 1984), the sociotechnical transitions theory (Geels and Schot, 2007; Geels, 2019), and actor-network theory (Latour, 2005). It also reviews examples of sociotechnical integration within existing engineering classrooms. Finally, it provides an argument that sociotechnical thinking can improve sustainability-focused engineering education. By more explicitly tying the strands of sustainability research and sociotechnical integration together, the goal of this paper is to identify where sociotechnical lenses can be used to create deeper understandings of sustainability within engineering students, even, and perhaps especially, in the absence of a single, quantitatively measurable definition of sustainability.

Introduction:

Sustainability is an increasingly important goal within engineering education (Allenby, 2009). However, "engineering sustainability" is difficult (impossible?) to define, and thus, can be difficult to implement in a meaningful way (Ramsey, 2015). Understanding the history and context behind terms like "sustainability" and "sustainable development" can help engineers to understand their role within these movements.

This narrative literature review argues for the application of a sociotechnical lens to the notion of engineering sustainability to achieve a stronger, more holistic view of sustainability and to improve student learning. I will begin by providing a brief history of the terms: sustainability, sustainable development, and engineering sustainability. The terms are distinct, but related, and thus, I will provide a small overview of each. I will then show how engineering sustainability is implemented within the classroom, focusing especially on the teaching of Life Cycle Assessments. After that, I will briefly introduce sociotechnical thinking by detailing three prominent theories: Pinch and Bijker's Social Construction of Technology, Frank Geels and Johan Schot's sociotechnical transitions theory, and Bruno Latour's Actor-Network theory. I will provide some examples of sociotechnical integration within the engineering classroom. Finally, I will argue how and why a sociotechnical lens can strengthen engineering sustainability, focusing first on the ideological and value-based overlaps, and then moving into practical applicability.

I will conclude by providing an example of how sociotechnical integration has been implemented within sustainability curriculum, and then by providing a future direction for applying a sociotechnical lens to an existing engineering sustainability practice.

Origins of Engineering Sustainability:

When working to understand engineering sustainability, it helps to first take a step back and understand the history of sustainability as a whole. The use of the word "sustainability" in Google Books took off rapidly in around 1975, shown by Google Books Ngram viewer (Michel et al., 2010). While the use of the term "sustainability" is relatively recent, the concept has existed for far longer and developed separately within different disciplines. Some of the roots of sustainability come from ecology, technological skepticism, resource management, and ecodevelopment (Kidd, 1992). Due to these different roots, "sustainability" does not have a single definition. This lack of definition should not undermine the value of the word, but rather, encourage people to be specific when operationalizing the term (Ramsey, 2015).

An important related term is "sustainable development". Like sustainability, sustainable development lacks a strict universal definition, and some scholars argue that the concept itself is contradictory (Redclift, 2005; Spaiser et al., 2017). However, the most common definition of sustainable development comes from Our Common Future, also known as the Brundtland report. While the entire report is nearly 400 pages long, and includes an array of social, ethical, and environmental considerations, the definition of sustainable development that has traveled farthest is "development which meets the needs of the present without compromising the ability of future generations to meet their own needs" (Brundtland, 1987, p. 24). The Brundtland Report has more than 13,000 citations on Google

Scholar, demonstrating its widespread use. The Brundtland definition of sustainable development has been applied in an array of contexts, and often, the applications may be mutually exclusive or contradictory (Redclift, 2005). Without an understanding of the history of sustainability, or the context of the remainder of the report, this definition alone does not account for normative values or environmental protection. To classify some of the broad interpretations of sustainability and sustainable development, some scholars outline differences between weak and strong sustainability (Baker, 2006, Neumayer, 2025). Weak sustainability is typically associated with a lack of ethical values or considerations of equity. Crucially, weak sustainability upholds principles of *substitutability*—the idea that services or capital provided by the natural environment can be replaced with human-made services and resources. However, some natural capital cannot be replaced with human-made capital, and conserving natural capital for future generations is an important consideration of intergenerational justice (Reijnders, 2021, Neumayer, 2025).

The principle of substitutability is often included within engineering sustainability. For example, one group of researchers propose the concept of desalination through solar energy as a step towards sustainability (Gude et al, 2011). While novel, in this conception of sustainability, a natural resource (freshwater) is being substituted with man-made capital (desalination technology to utilize saline water). While engineering sustainability does exhibit some range in definition, it is often associated with weak sustainability. The tenets of weak sustainability tend to be in line with the traditional roles of engineers within society—practical and pragmatic technical experts whose professional training may be void of holistic ethical and equity concerns (Allenby et al., 2009). For example, one paper titled *Engineering Sustainability: A Technical Approach to Sustainability* by Marc Rosen attempts to define "engineering sustainability". The author cites the Brundtland report for the basic definition of sustainability and built on it to propose a definition for engineering sustainability. Rosen's proposed tenets of engineering sustainability focus largely on what is deemed "technical", with "fulfillment of other aspects of sustainability" (Rosen, 2012, p. 2274) as a goal that addressing technical problems is likely to achieve. These "technical" issues include sustainable resources, sustainable processes, increased efficiency, and reduced environmental impact (Rosen, 2012). Importantly, Rosen does not intend to diminish the value of the "social" aspects of sustainability—rather, he asserts that solving the "technical" problems will make solving the other problems easier. He also identifies a Life Cycle Assessment (LCA) as a tool which can help to promote engineering sustainability.

Current Implementations of Engineering Sustainability:

Teaching students about LCA is a common technique for implementing sustainability initiatives within the engineering classroom. LCA quantifies the environmental impact of a product over its lifetime, considering impacts related to raw materials, transportation, manufacturing processes, and disposal. Its general methodology includes goal and scope definition, inventory analysis, impact assessment, and interpretation. LCA is typically performed using a software, which may be created by the user or commercially available. It is a practice commonly used by practitioners and has become a prominent sustainability exercise within the classroom. For example, one group of researchers designed and introduced an LCA platform to a postgraduate interdisciplinary class. While the students found the software helpful in comparing environmental outcomes of different waste disposal design options, some students were cautious to report results of the model without knowing where all the data came from (Burnley et al., 2019). In another example, students are instructed to use a commercially available LCA software (GaBi) to analyze the environmental impacts of a steel door hanger, considering potential impacts from the raw material phase to the disposal phase (Tseng et al., 2021).

While LCA holds merit to compare environmental impacts of different alternatives, there are several concerns associated with LCA, including its lack of attention to social factors, which often cannot be reduced to quantifiable domains (Guinée et al., 2011). Another major concern with LCA as a practice was raised by a student in Burnley's study, exemplified by the following quote: "I've got answers, but I can't defend them" (Burnley et al., 2019, p. 74). This student's discomfort with reporting environmental impacts based on data they cannot see is rooted in an important limitation of LCA—there are underlying assumptions and decisions made, which are often abstracted and invisible to the user.

One study found that different LCA software produced different environmental impact values for the same process, executed by the same users (Lopes Silva et al., 2019). The outputs from LCA software may seem to be straightforward, quantitative, and indisputable based on the way they portray results. Different software yielding different results confirms the existence of methodological differences due to human-made decisions. The data was collected and input *by people*. The outputs of the software will be used and interpreted *by people*. Even with processes that appear straightforward and technical like LCA, assessing the sustainability of a process or product is a human-centered, socially constructed process.

Outside of LCA, other methods of teaching sustainability in engineering classrooms have been found to fall short. Two literature reviews (a scoping and a systematic review, respectively) have been conducted to assess the landscape of sustainability within engineering education (Gutierrez-Bucheli et al., 2022; Sundman et al., 2025). Both found that experiential and project-based learning are common approaches to this initiative. However, these attempts are often lacking in broad interdisciplinarity, are elective courses, or do not inspire deep transformative learning in students.

For the sake of embracing strong sustainability and encouraging transformative student experiences, I argue that the engineering discipline must adopt a broader understanding of sustainability. While engineers often do not intend to diminish the value of the "social" aspects of sustainability, they may assert that solving the "technical" problems will make solving the other problems easier. The idea that technology is separate from society—or that social values are extricable from technological development—is sometimes called a social-technical dualism (Faulkner, 2000). The rejection of social-technical dualisms is a core tenet of *sociotechnical* thinking. I will begin by explaining what I mean by sociotechnical thinking, and then I will explain how and why I believe this lens can strengthen engineering sustainability.

Sociotechnical Systems:

When referring to sociotechnical systems, scholars may either be referring to an intellectual space without strict boundaries, or to the more constrained disciplinary field of Science and Technology Studies, or STS. Within STS and engineering education research, a sociotechnical *lens* can be defined as "the study of the processes by which scientific knowledge and technological artifacts are constructed (developed, maintained, and changed) and also the study of the changes in the broader social and material worlds that occur as part of the mutual shaping, co-constitution, or coproduction of science and technology with society and the natural environment" (Hess and Sovacool, 2020, p.1). A sociotechnical lens encompasses a broad set of theories which share a common goal to explain "the adoption, use, acceptance, diffusion or rejection of new technology" (Sovacool and Hess, 2017, p. 704). Several important theories which assume sociotechnical lenses include the Social Construction of Technology (Pinch and Bijker, 1984), the theory of sociotechnical transitions (Geels, 2019), and Actor-Network theory (Latour, 2005).

The Social Construction of Technology (SCOT) is a theory proposed by Pinch and Bijker which positions society as a driver of technology, as opposed to more deterministic viewpoints (Pinch and Bijker, 1984; Winner, 1985). A distinguishing factor of this theory is its attention various social groups involved in the development of new technologies. As relevant social groups define problems, the proposed solutions will shift, which alters the development of the artifact. A hallmark of SCOT is its expanding "web" of artifact development, showing how the evolution of a technology can shift depending on the needs and desires of different social groups. This web challenges the idea that technology develops linearly. However, as social negotiations, uses, meanings, and designs of technologies begin to stabilize, aspects of a technology can begin to seem “natural”. Mechanisms of closure can be achieved through real or perceived solutions to proposed problems, or through problem redefinition (Pinch and Bijker, 1984).

The sociotechnical transitions theory is an expansion of the “multi-level perspective”, which is a sociotechnical approach focused on systems, proposed by Frank Geels and Johan Schot (Geels and Schot, 2007; Geels et al., 2017a). This theory defines sociotechnical regimes as entrenched shared rules and institutions. While acknowledging and emphasizing the importance of “radical innovations”, the sociotechnical transitions theory is also rooted in the idea that sociotechnical changes happen as social groups engage in activities in unique contexts. Geels also identifies different “lock-in mechanisms” (2019, p. 189) which impact the development, evolution, and adoption of new technologies. These include technoeconomic, social and cognitive, and institutional and political lock-in mechanisms. In other words, a technology may fail to be adopted for several reasons, which are not limited to its mere technological merits (Geels, 2019).

Another way scholars have theorized sociotechnical systems is through actor-networks, specifically actor-network theory (ANT). ANT is a theory, first proposed by Bruno Latour, which positions humans and non-humans alike as actors who interact within a network (2005). This framing allows for a broader consideration of stakeholders, which includes non-human actors. An important feature of this theory is that it can help to provide a better understanding of the “black box” of technological development. By examining actors equally as they interact within systems, one can start to understand whose values are ultimately implemented and in what way. ANT has travelled widely as a theory and has been used in numerous engineering (Rodrigues et al., 2022; Irish and Romkey, 2021) and sustainability (Bell, 2022) contexts.

A common feature of the above (and most) sociotechnical theories is the rejection of social-technical dualisms (Faulkner, 2000) and technological determinism (Winner, 1985). Some common values of a sociotechnical lens include embracing broader interdisciplinarity and challenging traditional notions of rigor (Riley, 2017). While challenging social-technical dualisms and embracing interdisciplinarity in engineering spaces can be difficult, several scholars have worked to promote sociotechnical integration within the classroom. Sociotechnical integration is an increasingly important goal for both students and educators (Romkey, 2023; Özkan & Andrews, 2022).

Sociotechnical Integration:

Sociotechnical integration is a crucial piece of creating socially conscious and ethically responsible engineers. In a multi-university study with 326 participants, Erin Cech found that traditional engineering programs may foster cultures of disengagement. Cech found that engineering students entered their degree emphasizing “technical” aspects (e.g. math and science, invention, etc.) over engagement-related aspects such as ethical or social issues. She also found that these disparities increased over the course of the student’s enrollment in an engineering program (Cech, 2014). Her findings suggest that sociotechnical integration within the classroom may produce more socially conscious engineers. Furthermore, it has been found that sociotechnical integration within the classroom can help to foster a culture of engagement by helping students to identify and grapple with the social aspects and real-world implications of complex problems (Özkan, 2026). However, students often lack these sociotechnical experiences if they are not intentionally embedded within the curriculum. For example, one study found that engineering students showed similar levels of technical competency to practitioners but lacked the sociotechnical skills that professional engineers have. While engineering practitioners were found to engage with human-centered issues and broad contextual factors, engineering students lacked these competencies (Mazzurco, 2020).

Sociotechnical integration can be a challenge in engineering, in part due to the heavy courseload associated with the degree. One group of researchers at Lafayette college challenged traditional disciplinary boundaries by integrating liberal arts and engineering. Part of the way that they were able to do this was by reducing the number of credits required by engineering students, as well as the number of math and science courses. The researchers also attempted to combine STS scholarship with engineering education by offering an Introduction to Engineering course that encourages first-year engineering students to think deeply about engineering as a sociotechnical practice (Cohen & Sanford, 2014). Another method which has been used to integrate sociotechnical thinking within the curriculum is the implementation of a “design spine”, which vertically integrates sociotechnical thinking across all four years of engineering curriculum. To achieve sociotechnical integration within the hard science classes, Salinas and Nieusma propose the use of techniques such as open-ended problem solving and evaluating boundary conditions of engineering problems (Salinas and Nieusma, 2024). Some educators address sociotechnical integration within intro courses. For example, one group of researchers encouraged undergraduate students to engage with social and political aspects of energy issues by participating in debates with classmates (DeWaters et al., 2021). Evidently, sociotechnical integration has become an increasingly important and common goal within engineering education. I propose that sociotechnical integration within sustainability focused-engineering education would promote a stronger version of engineering sustainability. While current engineering sustainability may lack attention to normative or social values, sociotechnical integration has been found to foster more socially conscious engineers.

Sociotechnical Thinking and Sustainability Values:

Sociotechnical thinking and sustainability education are highly compatible initiatives, both ideologically and practically. From an ideological standpoint, many sociotechnical theories, including SCOT, sociotechnical transitions theory, and ANT can be readily applied within sustainability contexts. Furthermore, key overlaps in values allow for the two disciplines to work together harmoniously, such as embracing interdisciplinarity and rejecting social-technical dualisms and traditional notions of rigor (Riley, 2017).

The SCOT framework is a sociotechnical theory one can use when looking at the development of sustainable technology. For instance, one group of researchers used an extension of the SCOT framework to understand community opposition to a wind project in Sandbridge Beach, Virginia (Friday & Özkan, 2025). Because the initial SCOT framework proposed by Pinch and Bijker was mainly intended to analyze the development of an artifact after stabilization has been reached, the authors also relied on an extension of the theory which allowed for interpretation of artifacts that were still being constructed (Pinch & Bijker, 1984; Humphreys, 2005). The researchers found that Kitty Hawk North, a wind project with technological merit was heavily contested by residents of the area. Using the SCOT framework allowed the researchers to identify the problems posed by the different social groups. Ultimately, they found a gap between the problems being identified by the users of the artifact (lack of trust in the developer, threats to tourism and economy, and contextual environmental impacts) and the solutions proposed by the developer (providing additional facts about the specific merits of the project). Evidently, the SCOT framework can be applied at a smaller scale, to individual projects, and its application can help to account for some of the social and cultural aspects of sustainability that engineers or developers may miss.

On a more macro-level scale, society-wide sustainable processes such as the energy transition can be analyzed using the sociotechnical transitions theory. In his article, *The cultural barriers to renewable energy and energy efficiency in the United States*, Benjamin Sovacool outlines barriers to renewable energy. Sovacool identifies these barriers as public apathy and misunderstanding, conceptions about abundance and consumption, and psychological factors (2009). Public apathy and misunderstanding stems from people's distance from power plants, which is often by design, and removes people from the negative impacts of electricity generation. Additionally, people don't tend to view electricity as a "technology"; they tend to view it as a fact of life (Sovacool, 2009). This is an example of how beliefs and values can be embedded within seemingly apolitical technologies (Latour et al., 1992). Sovacool identifies conceptions about consumption as America's overall beliefs about nature as something that man has dominion over (2009). Finally, psychological factors such as freedom of choice, control, the human desire to uphold the status quo, and trust, are barriers to renewable energy initiatives. In essence, Sovacool argues that cultural barriers play a much greater role in the energy transition than we often consider, and even a greater role than technical barriers. The barriers outlined by Sovacool show considerable overlap with the idea or technoeconomic, social and cognitive, and institutional and political lock-in mechanisms proposed by Frank Geels (Geels, 2019). Sovacool and Geels have also published together, writing about the sociotechnical transitions and dynamics required to achieve a low carbon energy transition (Geels et al., 2017b). Arguably, a sustainable energy transition must assume a sociotechnical lens, as technical innovation alone is not enough to overcome the current system which is culturally "locked in" to place (Geels, 2019, p. 189).

Finally, Sarah Bell suggests ANT provides a framework which can help to promote the agency of natural resources (2022). By blurring the line between human and non-human and thinking in terms of networks, ANT can help to promote a strong conceptualization of sustainability that recognizes the intrinsic value of nature, rather than just its utility to humans (Bell, 2022). One group of professors implemented these principles within their engineering curriculum, by having students apply ANT to a gas pipeline and a coal plant as case studies (Irish and Romkey, 2021). Irish and Romkey found that ANT can help students think deeply about sociotechnical aspects of sustainability, and that students continued to implement ANT beyond where it was required for course credit (2021).

Integrating Sociotechnical Sustainability:

Practically, sociotechnical integration can be applied to the sustainability landscape in several ways—one of which is by using energy systems as an entry point. Energy systems are an important part of engineering sustainability, and already commonly at the forefront of sustainability conversations. Energy systems are also a powerful example to expose students to sociotechnical systems (Özkan et al., 2026). The idea that energy systems have values embedded can become quickly apparent to students as they consider the ease of flipping a light switch and the relative distance that most societies are situated from power plants (Sovacool, 2009). Additionally, energy systems can provide an important set of problems in which boundary conditions can be explored in engineering science courses (Salinas and Nieusma, 2024). Importantly, sociotechnical theories can be applied to both renewable energy technologies and to the larger scale energy transition.

One example of a paper that applies a sociotechnical lens to engineering sustainability is titled *Insights and implications from a sociotechnical case study approach in sustainability education* by Koopman, et al. (2025). This article describes an instance of implementing a sociotechnical case study in an engineering classroom. The case study explores a wind project that failed to be built in Hawai'i. In this case study, students were informed of the community opposition to the project and subsequently roleplayed as different stakeholders. This helped students to understand some of the complexities of technologies. Following the role-playing activity, students had to answer the following questions (Koopman, et al. 2025, p. 173):

Q1. When looking at real-world complex situations with specific technical and social circumstances like in the Big Wind case, whose perspective do you think should be prioritized? Why?

Q2. Do you think the failure of the Big Wind project was the morally right outcome? Do you think the failure of the Big Wind project was an engineering failure or success? Explain your answer.

Q3. What do you think the case brought to the class? How did the case solidify, change, or expand your understanding of sustainable energy solutions?

These questions prompted an array of answers, with many, but not all, students showing an understanding of social dimensions in engineering problems. The authors concluded that case studies can be an effective method to teach engineers about the social and technical dimensions in engineering. This case study, and especially the set of follow-up questions, is unique because of its focus on the moral considerations of the project. It is also unique because it examines renewable energy, an initiative that is usually thought of as sustainable from an engineering standpoint.

Similarly, I propose that a sociotechnical lens can be applied to existing sustainability initiatives such as an LCA. A sociotechnical lens may help students to interrogate what values are "baked in" to an engineering process that seems technical and concrete. Students can begin to view the development of LCA as socially constructed, identifying which problems LCA initially sought to solve, and by which social groups these problems were initially raised by. From there, students can evaluate whether LCA truly addresses these problems, or if there is a mismatch between the solution and the problem. I believe that applying a sociotechnical lens to an existing engineering sustainability process can help students to move beyond narrow conceptions of sustainability and towards more holistic understandings. Furthermore, I believe that this would provide a transformative learning experience for students, as it builds upon their current knowledge and experience, and unsettles some of their existing beliefs.

Conclusions:

While sustainable engineering is an important goal for students, engineering instructors, and broader society, it is often hard to define and implement. “Sustainability” has a rich multidisciplinary history, which often proves challenging for engineers, who may adhere to rigid disciplinary boundaries (Riley, 2017). Thus, conceptions of engineering sustainability have at times come up short, often falling in line with “weak sustainability” (Baker, 2006 and Neumayer, 2025), and failing to inspire transformative learning in students (Gutierrez-Bucheli et al., 2022; Sundman et al., 2025). One common initiative for promoting sustainable engineering education is by having students conduct Life Cycle Assessments (LCA). However, LCA assumes a narrow view of sustainability, and can promote misconceptions of a value-neutral sustainability metric.

A potential antidote to the shortcomings of engineering sustainability is assuming a sociotechnical lens and prioritizing sociotechnical integration within engineering sustainability initiatives. Sociotechnical theories can be applied within sustainability contexts, from project-scale to society-wide initiatives. Furthermore, energy systems can serve as a useful entry point for both sociotechnical integration and sustainability education.

Finally, I propose that a sociotechnical lens can be applied to current engineering sustainability initiatives, such as LCA, to build off students’ existing knowledge, and allow them to question some of their existing beliefs. I believe that this exercise would provide a transformative learning process for students, allowing them to gain a better understanding of both sociotechnical thinking and strong sustainability.

References:

Allenby, B., Murphy, C. F., Allen, D., & Davidson, C. (2009). Sustainable engineering education in the United States. *Sustainability Science, 4*(1), 7–15. https://doi.org/10.1007/s11625-009-0065-5.

Baker, S. (2006). *Sustainable Development (1st ed.).* Routledge. https://doi.org/10.4324/9780203495933.

Bell, S. (2022). *Engineers, society, and sustainability*. Springer Nature. https://doi.org/10.1007/978-3-031-02110-7.

Brundtland, G. H. (1987). *Our common future world commission on environment and development*.

Burnley, S., Wagland, S., & Longhurst, P. (2019). Using life cycle assessment in environmental engineering education. *Higher Education Pedagogies,* 4(1), 64-79. https://doi.org/10.1080/23752696.2019.1627672.

Cech, E. A. (2014). Culture of Disengagement in Engineering Education? *Science, Technology, & Human Values*, *39*(1), 42–72. https://doi.org/10.1177/0162243913504305.

Cohen, B., Rossmann, J., & Sanford Bernhardt, K. (2014). Introducing Engineering as a Socio-technical Process. In *2014 ASEE Annual Conference & Exposition Proceedings* (p. 24.807.1-24.807.14). ASEE Conferences. 2014 ASEE Annual Conference & Exposition. https://doi.org/10.18260/1-2--20699.

DeWaters, J., Powers, S., & Bilow, F. (2021). An introductory energy course to promote broad energy education for undergraduate engineering students. *Sustainability*, 13(17), 9693. https://doi.org/10.3390/su13179693.

Faulkner, W. (2000). Dualisms, Hierarchies and Gender in Engineering. *Social Studies of Science*, *30*(5), 759–792. https://doi.org/10.1177/030631200030005005.

Friday, M & Özkan, D. S. (2025). Sociotechnical Development of Offshore Wind: A Case of Kitty Hawk North. 1-8. https://doi.org/10.1109/GHTC66843.2025.11266570.

Geels, F.W. & Schot, J. (2007). Typology of sociotechnical transition pathways. *Research Policy, 36*(3), 399-417. https://doi.org/10.1016/j.respol.2007.01.003.

Geels, F. W., Sovacool, B. K., Schwanen, T., & Sorrell, S. (2017). Sociotechnical transitions for deep decarbonization. *Science, 357*(6357), 1242–1244. https://doi.org/10.1126/science.aao3760.

Geels, F. W., Sovacool, B. K., Schwanen, T., & Sorrell, S. (2017b). The socio-technical dynamics of low-carbon transitions. *Joule, 1*(3), 463-479. https://doi.org/10.1016/j.joule.2017.09.018.

Geels, F. W. (2019). Socio-technical transitions to sustainability: a review of criticisms and elaborations of the Multi-Level Perspective. *Current Opinion in Environmental Sustainability, 39*, 187–201. https://doi.org/10.1016/j.cosust.2019.06.009.

Gude, V. G., Nirmalakhandan, N., & Deng, S. (2011). Desalination using solar energy: Towards sustainability. *Energy, 36*(1), 78-85. https://doi.org/10.1016/j.energy.2010.11.008.

Guinée, J. B., Heijungs, R., Huppes, G., Zamagni, A., Masoni, P., Buonamici, R., Ekvall, T., & Rydberg, T. (2010). Life Cycle Assessment: Past, Present, and Future. *Environmental Science & Technology, 45*(1), 90–96. https://doi.org/10.1021/es101316v.

Gutierrez-Bucheli, L., Kidman, G., & Reid, A. (2022). Sustainability in engineering education: a review of learning outcomes. *Journal of Cleaner Production, 330,* Article 129734. https://doi.org/10.1016/j.jclepro.2021.129734.

Hess, D. J., & Sovacool, B. K. (2020). Sociotechnical matters: Reviewing and integrating science and technology studies with energy social science. *Energy Research & Social Science, 65*, 101462. https://doi.org/10.1016/j.erss.2020.101462.

Humphreys, L. (2005). Reframing Social Groups, Closure, and Stabilization in the Social Construction of Technology. *Social Epistemology, 19*(2–3), 231–253. https://doi.org/10.1080/02691720500145449.

Irish, R., & Romkey, L. (2021). USING ACTOR NETWORK THEORY TO EXPLORE SUSTAINABILITY ISSUES IN AN ENGINEERING & SOCIETY COURSE. *Proceedings of the Canadian Engineering Education Association (CEEA).* https://doi.org/10.24908/pceea.vi0.14960.

Kidd, C. V. (1992). The evolution of sustainability. *Journal of Agricultural and Environmental Ethics, 5*(1), 1–26. https://doi.org/10.1007/bf01965413.

Koopman, K., Mosyjowski, E. A., Daly, S. R., Skerlos, S. J., & Syal, S. M. (2025). Insights and implications from a sociotechnical case study approach in sustainability education. *International Journal of Sustainability in Higher Education, 26*(9), 169–187. https://doi.org/10.1108/ijshe-01-2024-0007.

Latour, B. (2005). Reassembling the Social. Oxford University PressOxford. https://doi.org/10.1093/oso/9780199256044.001.0001.

Latour, B., Bijker, F. W. E., & Law, J. (1992). 10 "'Where Are the Missing Masses? The Sociology of a Few Mundane Artifacts.

Mazzurco A, D.S. (2020). Socio-technical thinking of students and practitioners in the context of humanitarian engineering. *Journal of Engineering Education.* 109: 243261. https://doi.org/10.1002/jee.20307.

Michel, J.-B., Shen, Y. K., Aiden, A. P., Veres, A., Gray, M. K., Pickett, J. P., Hoiberg, D., Clancy, D., Norvig, P., Orwant, J., Pinker, S., Nowak, M. A., & Aiden, E. L. (2011). Quantitative Analysis of Culture Using Millions of Digitized Books. *Science, 331*(6014), 176–182. https://doi.org/10.1126/science.1199644.

Neumayer, E. (2025). *Weak versus Strong Sustainability.* Edward Elgar Publishing. https://doi.org/10.4337/9781035327898.

Ozkan, D., & Andrews, C. (n.d.). Perspectives of Seven Minoritized Students in a First-Year Course Redesign toward Sociotechnical Engineering Education. In *2022 ASEE Annual Conference & Exposition Proceedings*. *ASEE Conferences*. *2022 ASEE Annual Conference & Exposition*. https://doi.org/10.18260/1-2--41382

Özkan, D. S. (2026). Sociotechnical curricular approaches for a culture of engagement in engineering: students navigating power and equity. *Engineering Studies,* 18(1), 56-81.https://doi.org/10.1080/19378629.2025.2556386.

Özkan, D. S., Campbell, T., & Detrois, P. (2026). Engaging the Complexities of Energy Transitions: Sociotechnical and Dualistic Insights From Crossdisciplinary Undergraduates. *Science Education*. https://doi.org/10.1002/sce.70068.

Pinch, T. J., & Bijker, W. E. (1984). The Social Construction of Facts and Artefacts: or How the Sociology of Science and the Sociology of Technology might Benefit Each Other. *Social Studies of Science, 14*(3), 399–441. https://doi.org/10.1177/030631284014003004.

Ramsey, J. L. (2015). On Not Defining Sustainability. *Journal of Agricultural and Environmental Ethics, 28*(6), 1075–1087. https://doi.org/10.1007/s10806-015-9578-3.

Reijnders, L. (2021). Substitution, natural capital and sustainability. *Journal of Integrative Environmental Sciences,* 18(1), 115–142. https://doi.org/10.1080/1943815X.2021.2007133

Bezerra Rodrigues, R. A., Seniuk Cicek, J., Zacharias, K., & Paul, J. (2022). How Actor-Network Theory Travels and Changes in Engineering Education: A Narrative

Literature Review. In *2022 ASEE Annual Conference & Exposition Proceedings. ASEE Conferences. 2022 ASEE Annual Conference & Exposition.* https://doi.org/10.18260/1-2--41682.

Romkey, L. (2023). Instructor Goals and Practices Related to Sociotechnical Thinking in the Teaching of Undergraduate Engineering Students. *In 2023 ASEE Annual Conference & Exposition Proceedings. ASEE Conferences. 2023 ASEE Annual Conference & Exposition.* https://doi.org/10.18260/1-2--43740.

Rosen, M. A. (2012). Engineering Sustainability: A Technical Approach to Sustainability. *Sustainability, 4*(9), 2270–2292. https://doi.org/10.3390/su4092270.

Riley, D. (2017). Rigor/Us: Building Boundaries and Disciplining Diversity with Standards of Merit. *Engineering Studies*, *9*(3), 249–265. https://doi.org/10.1080/19378629.2017.1408631

Salinas, C., & Nieusma, D. (2024). Sociotechnical Integration as Programmatic Foundation in Engineering: Curriculum Design and ABET Assessment Protocols. In *2024 ASEE Annual Conference & Exposition Proceedings. ASEE Conferences. 2024 ASEE Annual Conference & Exposition*. https://doi.org/10.18260/1-2--47984.

Sovacool, B. K. (2009). The cultural barriers to renewable energy and energy efficiency in the United States. *Technology in Society, 31*(4), 365–373. https://doi.org/10.1016/j.techsoc.2009.10.009.

Sovacool, B. K., & Hess, D. J. (2017). Ordering theories: Typologies and conceptual frameworks for sociotechnical change. *Social Studies of Science, 47*(5), 703–750. https://doi.org/10.1177/0306312717709363.

Lopes Silva, D. A., Nunes, A. O., Piekarski, C. M., da Silva Moris, V. A., de Souza, L. S. M., & Rodrigues, T. O. (2019). Why using different Life Cycle Assessment software tools can generate different results for the same product system? A cause–effect analysis of the problem. *Sustainable Production and Consumption, 20*, 304–315. https://doi.org/10.1016/j.spc.2019.07.005.

Sundman, J., Feng, X., Shrestha, A., Johri, A., Varis, O., & Taka, M. (2025). Experiential learning for sustainability: a systematic review and research agenda for engineering education. *European Journal of Engineering Education*, 1–31. https://doi.org/10.1080/03043797.2025.2532591.

Tseng, T.-L., Rahman, M. F., Chiou, R., & Ho, J. (2021). Sustainable Green Design and Life Cycle Assessment for Engineering Education. In *2021 ASEE Virtual Annual*

Conference Content Access Proceedings. *ASEE Conferences*. *2021 ASEE Virtual Annual Conference Content Access*. https://doi.org/10.18260/1-2--37794.

Winner, L. (2017). Do Artifacts Have Politics? In *Computer Ethics* (pp. 177–192). Routledge. https://doi.org/10.4324/9781315259697-21.