Engineering Educators Bringing the World Together
2025 ASEE Annual Conference & Exposition
Palais des congrès de Montréal, Montréal, QC • June 22–25, 2025
Paper ID #45927

Measuring practical energy literacy: Exploring current scales' applicability to understand engineering students' energy knowledge

Samantha Splendido, Pennsylvania State University

Samantha Splendido is a Ph.D. candidate in Mechanical Engineering at Pennsylvania State University. She is currently a graduate research assistant under Dr. Catherine Berdanier in the Engineering Cognitive Research Laboratory (ECRL) and a graduate teaching fellow in the Penn State Department of Mechanical Engineering. Samantha earned her B.S. in Biomedical and Mechanical Engineering and her M.S. in Mechanical Engineering from Pennsylvania State University.

Vaishnavi Wagh, Pennsylvania State University
Catherine G. P. Berdanier, The Pennsylvania State University

Catherine G.P. Berdanier is an Associate Professor of Mechanical Engineering at Pennsylvania State University. She earned her B.S. in Chemistry from The University of South Dakota, her M.S. in Aeronautical and Astronautical Engineering and her PhD in Engineering Education from Purdue University. Her research expertise lies in characterizing graduate-level attrition, persistence, and career trajectories; engineering writing and communication; and methodological development.

Measuring practical energy literacy: Exploring current scales' applicability to understand engineering students' energy knowledge

Abstract

The purpose of this empirical research brief paper is to analyze current energy literacy research for assessing literacy within domain-specific contexts. Most research knowledge surrounding energy literacy is focused on understanding how well individuals understand energy production, consumption, and conservation from a general energy perspective. However, engineers' energy literacy typically requires a more focused and practical competency, since engineers are at the forefront of energy technology development, use, and improvement. Equipping future engineers with practical energy knowledge prior to entering their careers can improve the technology they produce. Exploring energy literacy at the undergraduate level will better prepare students for energy-related careers, improve educational experiences, and help internalize practical energy knowledge. To understand how prepared undergraduate engineering students are for future careers in energy-related industries, measuring energy literacy in students can provide greater insights for understanding and improving practical energy literacy development. This brief explores current energy literacy scales' transferability to measure energy literacy within specific domains as well as key indicators of quality and reliability for future scale development and assessment. From our review of current scales, we explore areas where change is necessary to capture undergraduate engineering students' domain-specific energy literacy.

Keywords: energy literacy, undergraduate research, energy education

Introduction and Literature Review

The United States and countries worldwide have identified the need to reassess energy generation and consumption due to the constantly increasing energy demand. As technology advances in an attempt to meet new energy needs, research has also brought a need for knowledge of energy sources, with concentrated efforts on sustainability and renewables, as well as understanding energy consumption. Current energy production relies heavily on non-renewable and climate impactful sources like oil, natural gas, and coal, with over 80% of the US's energy produced from fossil fuels [1]. Sustainable energy sources have steadily increased in usage, but development and adoption of sustainable technologies is still far behind necessary levels to meet emission reduction goals by 2050 [2],[3]. In addition to developing and using sustainable technologies, reducing energy consumption has been discussed as an opportunity to decrease reliance on non-renewable sources and emissions. Engineers are typically at the forefront of these technological developments, indicating that the next generation of sustainable energy technology will need sustainability and energy literate engineers. While sustainability literacy has expanded within engineering domains [4]-[7], energy literacy is understudied in engineering. However, for technological advancements to occur in energy-related fields, energy literacy is vital to their success.

The US has identified a significant lack of overall energy knowledge in the general population that may continue to hinder climate and sustainability goals in the future. The National Environmental Education & Training Foundation (NEETF) [8] found that Americans self-report high levels of energy knowledge but less than 12% can pass a basic energy knowledge quiz.

Researchers also found that this lack of knowledge is preventing discussions of energy and climate issues and could be an indicator of delayed economic progress into the future. In the report, NEETF identified the need for proper energy education in younger generations to help our future energy issues, prompting growth in energy literacy research and educational improvements. The US Department of Energy later established the energy literacy framework [9] to clearly define the concepts and principles that constitute energy literacy to be used in a wide variety of educational contexts including classrooms, learning programs, and other informal learning environments (e.g. museums). The framework emphasizes the importance of understanding basic energy concepts as well as understanding the influences of decision and policy-making on energy production and consumption.

Prior work on energy literacy and education has focused on secondary educational contexts [10]-[15], aligning with NEETF's recommendations and understanding the strong influence of traditional learning environments on energy education. These studies investigate energy literacy from a general energy knowledge perspective, investigating students' knowledge, attitudes, and behaviors for all components of the energy literacy framework, including household behaviors as a major component. DeWaters and Powers [12] found strong basic energy knowledge in middle and high school students but indicated a need for more practical energy literacy relating to energy production, saving, and household usage. Some post-secondary energy literacy research has also focused on general energy knowledge and its impact on individuals' attitudes and behaviors for sustainability [16]-[19]. Within engineering, limited research has been performed on undergraduate students' energy literacy. Nelson et al. [20] investigated energy literacy within an undergraduate engineering context, identifying similar knowledge gaps as DeWaters and Powers as well as a strong interest among students in learning more about sustainable and renewable energy technologies in their courses.

Literature strongly indicates that improving general energy literacy can assist with moving closer to sustainability goals and help individuals make more informed decisions on energy. Further, expanding energy literacy into domain-specific areas and emphasizing practical knowledge in engineering education has the potential to positively impact the energy industry and society well into the future. Prior work focused on energy literacy can still provide an important foundation for understanding domain-specific energy literacy as well as indicators to promote quality research methods for scale development and literacy assessment. To understand the current landscape of energy literacy measurements and its application into domain-specific research, we seek to reach the following research objectives:

1) How can current energy literacy studies investigate literacy with a domain-specific perspective?
2) What indicators of the cognitive domain are useful for studying energy literacy in domain-specific research?

Conceptual Framework

As a primary conceptual framework, we utilize Bloom's revised taxonomy [21], [22] to understand how current research establishes energy literacy measurement. Bloom's taxonomy was developed to establish learning objectives in educational contexts and has further been used to evaluate classes, assessments, and instruments for effectiveness [23]-[25]. We intend to use this framework to represent how current research has utilized goals related to learning to assess energy literacy in students and individuals. Bloom's revised taxonomy establishes cognitive, affective and psychomotor learning domains, and establishes six levels of cognitive learning: remembering, understanding, applying, analyzing, evaluating, and creating. The hierarchical structure showcases how acquiring knowledge builds up over time, allowing students to progress through initial levels of learning and reciting new information to employing their knowledge to decision making and creating. DeWaters and Powers [26] defined energy literacy in the cognitive domain as showing a basic understanding of energy and its everyday use as well as the impacts of energy production and consumption on individuals and society. However, the instruments must be adapted to measure technical or domain-specific energy literacy.

Methods

To investigate the current landscape of energy literacy research, we performed a systematic review of the literature for energy topics and literacy. Initial searches identified prior research utilizing scale items to collect and analyze individuals' understanding of energy literacy concepts with some environmental implications related to them. For the purposes of this brief, we focus on the cognitive domain to understand measures of energy knowledge. This search allowed for the collection of questionnaires, surveys, and concept inventories with a variety of question types. From this initial collection, each study was assessed for its application to our objectives, excluding studies that did not contain cognitive components in their energy literacy assessments. Relevant research was further reduced through assessing the survey items and development. Specifically, we eliminated studies that directly used or minimally adapted prior scales and instead collected the original surveys and questionnaires. After secondary analysis of the literature, we grouped the studies into similar categories related to their knowledge focus (e.g. domain-specific energy knowledge, general energy knowledge) and collected additional important scale attributes. Through this categorization, we identified common characteristics and how they may apply in a domain-specific context. Assessment was also performed using Bloom's revised taxonomy of the cognitive domain to determine the levels to which the research assessed energy literacy knowledge.

Limitations

We identify some limitations to the literature search performed in this research brief. To begin, we recognize that this brief does not represent a comprehensive list of all energy literacy scales developed due to the breadth of energy-related that has been conducted. Additionally, the research collected in this brief also contains multiple participant contexts that each may impact findings. Geographic location, in addition to participant demographics, may play an additional role in findings. Some studies included in this brief were conducted in countries outside of the US, which have their own unique and complex political, structural, and societal characteristics to energy education and policies that may impact findings. However, because climate change and sustainability are worldwide issues, it is important to include more perspectives to allow for our research to be applicable in these locations.

Energy Literacy Measures in Literature

In this section, we present our findings from the review of energy literacy literature. Through our search, we identified five scales to measure energy literacy with cognitive components to discuss. Table 1 presents the collected articles with their relevant attributes. We discuss each article based on their energy knowledge focus to identify common components of scales within these categories. Importantly, we discuss the scales within their general versus domain-specific energy knowledge focuses, this distinction relates to the depth of energy knowledge that the measurements seek to identify.

Table 1. Collected prior research for energy literacy measurement

Author (year)	Energy knowledge focus	Intended participants	Quantity of cognitive items	Taxonomy knowledge level assessed
DeWaters et al. (2013) [27]	General	Middle and high school students	Middle school: 30 out of 57 items High school: 38 out of 65 items	Remembering, understanding, applying, analyzing, evaluating
National Energy Foundation (2017) [28], [29]	General	High school seniors and recent graduates	28 out of 51 items	Remembering, understanding, applying, analyzing
Cotton et al. (2018) [30]	General	Undergraduate students	9 out of 32 items	Remembering, understanding, applying
Turner et al. (2014) [31]	Domain-specific (electric power)	US adults	89 out of 89 items	Understanding, applying, analyzing, evaluating
Prince et al. (2013) [32]	Domain-specific (engineering)	Undergraduate students	9 out of 36 items	Applying, analyzing, evaluating

General energy knowledge measurements. Measures of general energy knowledge make up a large majority of energy literacy literature. Numerous additional articles outside of those collected and presented in this brief analyzed the energy literacy of students, individuals, and households from a general energy knowledge perspective.

In many instances, these studies (e.g. [11], [19], [20], [33]-[36]) utilized and adapted the energy literacy questionnaire developed by DeWaters et al. [27], which has a relatively high quantity of cognitive items. Similarly, the National Energy Foundation (NEF) [28], [29] energy literacy survey has a high quantity of cognitive questions. The Cotton et al. [30] survey has fewer cognitive components but does contain similar questions to the other two surveys. All three surveys focus heavily on basic energy concepts and energy sources. Also, these surveys contain questions relating to energy consumption's impacts on climate change and human health, adhering to the definition and framework of energy literacy. Differences in findings from each surveys' distribution related heavily to the contexts of where the surveys were distributed. Each survey found that their participants had a high knowledge of basic energy concepts, but these studies' findings diverged as the depth of participants' energy knowledge was tested. Assessing questions from the lens of Bloom's revised taxonomy indicated all three surveys tested knowledge on the lower levels of the cognitive domain: remembering, understanding, and applying (e.g. asking participants to define what renewable energy source is or choose an example scenario that would reduce energy consumption). A few questions from DeWaters et al. and NEF extended into the analyzing and evaluating levels. Both studies found participants performed poorly on more specified questions, especially related to energy production and usage.

Domain-specific energy knowledge measurements. Energy literacy research focused on measuring domain-specific energy knowledge was, as anticipated, more difficult to collect. Surveys identified that did fit the domain-specific criteria contained some similarities, even though they did not focus on the same domains. Turner et al. [31] and Prince et al. [32] both focused in the cognitive domain, containing cognitive questions that included affective and behavioral components (e.g. questions relating to knowledge and attitudes relating to aging power grid infrastructure), but no questions explicitly developed for domains outside of cognitive.

In general, these studies asked questions that relied heavily within the applying, analyzing, and evaluating levels of knowledge from Bloom's revised taxonomy, building upon the lower levels of knowledge like remembering and understanding, but not asking questions that focused within those lower levels. Differences between these collected domain-specific studies are based heavily on the intentions of the surveys. Turner et al. [31]'s survey is intended for a wider population of US adults and to establish a concept inventory for energy and power grid knowledge. Basic energy knowledge questions are included in Turner et al.'s survey, but a majority of the questions require higher-level energy knowledge applied specifically to power grid use and infrastructure. While Prince et al. [32]'s goal is to also establish a concept inventory for heat and energy, their audience is focused on engineering students and improving heat and energy education. All items in Prince et al.'s survey are cognitive, but only nine relate to energy concepts. The rest of the questions focus further on heat concepts that do not have a direct relationship to energy literacy. However, Prince et al.'s work still provides information to guide future energy literacy research, especially identifying common misconceptions engineering students have about energy and its relationship to heat.

Discussion and Implications

Energy literacy research has maintained a focus on general knowledge perspectives, which are an important foundation for developing energy literate individuals. The research identified in this brief indicates that general energy knowledge measurement is valuable, especially in secondary and post-secondary education. Continuing to educate individuals on energy topics remains imperative to promote future sustainability goals and empowering climate conscious decision making. For application to domain-specific energy knowledge, many components of these general knowledge-focused surveys are useful. The most prevalent utility of these previous studies is the identified lack of knowledge of current energy sources and renewable energy. Identifying and improving potential misconceptions or knowledge gaps relating to energy production can provide a strong foundation for improving current technology for sustainability and developing new technology. Further, developing a stronger and more practical energy knowledge foundation within specific domains can better prepare students for future careers. Some researchers posit that the engineering educational system is still behind in preparing engineering students for careers in energy, especially in renewables [37], [38]. Educational systems adapting to new technologies and energy advancements can benefit all parties; graduating engineers can become more informed about the technology, engineering programs can remain at the forefront of energy technologies, and future employers can benefit from better prepared engineers. Thus, utilizing the methods and knowledge emphasis identified from previous scales to measure energy literacy in students can help develop measurements for future research on domain-specific energy literacy.

Energy literacy studies focused on domain-specific knowledge provide different perspectives on measuring energy knowledge while also showcasing how to combine knowledge with attitudes and behaviors. Particularly, incorporating attitudes and behaviors can assist with expanding how we test more practical energy knowledge into higher cognitive levels like analyzing, evaluating, and potentially even creating. These studies have helped identify that domain-specific research relies more on assessing knowledge at higher cognitive levels of Bloom's revised taxonomy for practical usage. If future employers expect engineers to be able to evaluate and create energy technologies, it is important for energy literacy measurements to assess whether students have developed the ability to do so during their energy education. All studies collected in this brief indicated strong scale development methods that may be useful to future energy literacy scales. Namely, most studies utilized large quantities of cognitive items, emphasizing the importance of energy knowledge, whether general or domain specific. Also, each scale's development methods were deeply rooted in both literature and field experts' input relating to the goals of the study, which would serve as strong references for future scale development. Key components of these scales' reliability promote rigorous validation methods such as industry professionals and expert validation panels, multiple rounds of pilot testing, and exploratory and confirmatory factory analyses scale items prior to deployment and assessment.

It is also important to recognize components of prior energy literacy work may not be necessary for domain-specific energy literacy. For example, many current studies in this brief have viewed practical energy knowledge to be day-to-day use and conservation of energy (e.g. understanding that plugged in appliances may still be consuming energy when not in use). While this component is important to general energy literacy, practical energy literacy in a domain-specific context like engineering will need to focus more on applications of energy knowledge within their fields to prepare for careers and develop technologies. Martins et al. [19] performed analyses of multiple general educational fields (e.g. environmental sciences, life sciences, engineering sciences) to compare their energy literacy. While findings did not have strong statistical significance, their preliminary data indicates that different fields may have different energy literacy. Understanding that various fields may emphasize energy concepts differently, the creation of more specialized measures of energy literacy can provide opportunities to make more intentional pedagogical changes to address specific gaps and improve student preparedness.

Conclusion

In this research brief, we have identified five energy literacy scales measuring energy knowledge in both general and domain-specific contexts. By focusing within the cognitive domain, we were able to identify important components of measuring energy knowledge within both contexts. Through this exploration of the literature, we also found scale development methods to assist with research as well as areas in general energy knowledge that would be useful to measure in a domain-specific context. Additionally, we further identified the need for domain-specific energy literacy research for use within engineering contexts to aid with technological developments. Future work will begin with development of a domain-specific energy literacy scale and further research into the impacts of improving energy literacy in engineers for sustainability and energy technologies. Further, future scales will be rigorously piloted, validated, and measured for reliability before being broadly utilized.

Acknowledgements

This material is based upon work supported by the National Science Foundation award # 2400672. Any opinions, findings, and conclusions or recommendations expressed in this material are those of the author(s) and do not necessarily reflect the views of the National Science Foundation.

References

[1] U.S. Energy Information Administration (EIA), "Total Energy: Monthly Energy Review."

[2] S. Sen and S. Ganguly, "Opportunities, barriers and issues with renewable energy development – A discussion," *Renewable and Sustainable Energy Reviews*, vol. 69, pp. 1170–1181, Mar. 2017, doi: 10.1016/J.RSER.2016.09.137.

[3] M. A. Hannan *et al.*, "Impact of renewable energy utilization and artificial intelligence in achieving sustainable development goals," *Energy Reports*, vol. 7, pp. 5359–5373, Nov. 2021, doi: 10.1016/J.EGYR.2021.08.172.

[4] C. Paten, N. Palousis, K. (Charlie) Hargroves, and M. Smith, "Engineering sustainable solutions: Education program - Putting sustainability as a 'critical literacy' into mainstream engineering curricula," *Proceedings of the 2004 International Conference on Engineering Education in Sustainable Development, EESD*, 2004.

[5] M. Lamere, L. Brodie, A. Nyamapfene, L. Fogg-Rogers, and V. Bakthavatchaalam, "Mapping and Enhancing Sustainability Literacy and Competencies within an Undergraduate Engineering Curriculum," in *REES AAEE 2021 Conference: Engineering Education Research Capability Development*, Perth, WA: Engineers Australia, 2021. [Online]. Available: https://search.informit.org/doi/10.3316/informit.347275650746649

[6] C. Zhou, "Developing creativity as a scientific literacy in software engineering education towards sustainability," *2016 12th International Conference on Natural Computation, Fuzzy Systems and Knowledge Discovery, ICNC-FSKD 2016*, pp. 2257–2261, Oct. 2016, doi: 10.1109/FSKD.2016.7603533.

[7] S. J. Sanchez, J. D. Ballen, M. J. R. Varon, and D. L. Robertson, "Associating Sustainability Literacy with educational level of Industrial Engineering Students," *ASEE Annual Conference and Exposition, Conference Proceedings*, Jun. 2024, doi: 10.18260/1-2--46626.

[8] The National Environmental Education & Training Foundation, "Americans' Low 'Energy IQ:' A Risk to Our Energy Future," Washington D.C., Aug. 2002.

[9] U.S. Department of Energy, "Energy Literacy: Essential Principles for Energy Education," Washington D.C., Mar. 2017. Accessed: Oct. 30, 2024. [Online]. Available: https://www.energy.gov/energysaver/energy-literacy-essential-principles-energy-education

[10] Y. Akitsu, K. N. Ishihara, H. Okumura, and E. Yamasue, "Investigating Energy Literacy and Its Structural Model for Lower Secondary Students in Japan.," *International Journal of Environmental and Science Education*, vol. 12, no. 5, pp. 1067–1095, 2017.

[11] L. S. Lee, Y. F. Lee, J. W. Altschuld, and Y. J. Pan, "Energy literacy: Evaluating knowledge, affect, and behavior of students in Taiwan," *Energy Policy*, vol. 76, pp. 98–106, Jan. 2015, doi: 10.1016/J.ENPOL.2014.11.012.

[12] J. E. DeWaters and S. E. Powers, “Energy literacy of secondary students in New York State (USA): A measure of knowledge, affect, and behavior,” *Energy Policy*, vol. 39, no. 3, pp. 1699–1710, Mar. 2011, doi: 10.1016/J.ENPOL.2010.12.049.

[13] J. DeWaters and S. Powers, “Energy literacy among middle and high school youth,” *Proceedings - Frontiers in Education Conference, FIE*, 2008, doi: 10.1109/FIE.2008.4720280.

[14] L. H. Barrow and J. T. Morrisey, “Energy Literacy of Ninth-Grade Students: A Comparison Between Maine and New Brunswick,” *J Environ Educ*, vol. 20, no. 2, pp. 22–25, 1989, doi: 10.1080/00958964.1989.9943027.

[15] S. C. Yeh, J. Y. Huang, and H. C. Yu, “Analysis of Energy Literacy and Misconceptions of Junior High Students in Taiwan,” *Sustainability 2017, Vol. 9, Page 423*, vol. 9, no. 3, p. 423, Mar. 2017, doi: 10.3390/SU9030423.

[16] D. R. E. Cotton, W. Miller, J. Winter, I. Bailey, and S. Sterling, “Developing students’ energy literacy in higher education,” *International Journal of Sustainability in Higher Education*, vol. 16, no. 4, pp. 456–473, Jul. 2015, doi: 10.1108/IJSHE-12-2013-0166.

[17] D. R. E. Cotton, J. Zhai, W. Miller, L. Dalla Valle, and J. Winter, “Reducing energy demand in China and the United Kingdom: The importance of energy literacy,” *J Clean Prod*, vol. 278, p. 123876, Jan. 2021, doi: 10.1016/J.JCLEPRO.2020.123876.

[18] A. Martins, M. Madaleno, and M. F. Dias, “Energy literacy assessment among Portuguese university members: Knowledge, attitude, and behavior,” *Energy Reports*, vol. 6, pp. 243–249, Dec. 2020, doi: 10.1016/J.EGYR.2020.11.117.

[19] A. Martins, M. Madaleno, and M. F. Dias, “Energy literacy: Does education field matter?,” *ACM International Conference Proceeding Series*, pp. 494–499, Oct. 2019, doi: 10.1145/3362789.3362938.

[20] M. Nelson, G. D. Hoople, J. A. Mejia, and D. A. Chen, “What is Energy? Examining Engineering Students’ Conceptions of Energy,” in *2020 ASEE Virtual Conference*, 2020.

[21] B. S. Bloom, M. D. Englehart, E. J. Furst, W. H. Hill, and D. R. Krathwohl, *Taxonomy of educational objectives: Handbook 1. Cognitive domain.* . White Plains, NY: Longman, 1956.

[22] D. R. Krathwohl, “A Revision of Bloom’s Taxonomy: An Overview,” *Theory Pract*, 2002.

[23] L. H. Waite, J. F. Zupec, D. H. Quinn, and C. Y. Poon, “Revised Bloom’s taxonomy as a mentoring framework for successful promotion,” *Curr Pharm Teach Learn*, vol. 12, no. 11, pp. 1379–1382, Nov. 2020, doi: 10.1016/J.CPTL.2020.06.009.

[24] W. Boles, D. Jayalath, and A. Goncher, “Categorising conceptual assessments under the framework for Bloom’s taxonomy,” *Proceedings of the 26th Annual Conference of the Australasian Association for Engineering Education (AAEE2015)*, 2015.

[25] A. J. Swart, "Evaluation of final examination papers in engineering: A case study using bloom's taxonomy," *IEEE Transactions on Education*, vol. 53, no. 2, pp. 257–264, May 2010, doi: 10.1109/TE.2009.2014221.

[26] J. DeWaters and S. Powers, "Establishing Measurement Criteria for an Energy Literacy Questionnaire," *J Environ Educ*, vol. 44, no. 1, pp. 38–55, Jan. 2013, doi: 10.1080/00958964.2012.711378.

[27] J. DeWaters, B. Qaqish, M. Graham, and S. Powers, "Designing an Energy Literacy Questionnaire for Middle and High School Youth," *J Environ Educ*, vol. 44, no. 1, pp. 56–78, Jan. 2013, doi: 10.1080/00958964.2012.682615.

[28] National Energy Foundation, "Energy Literacy Questionnaire," 2022.

[29] E. Richards, G. Swan, and D. Case, "National Energy Literacy Among High School Seniors and Recent Graduates," Salt Lake City, UT, Aug. 2017.

[30] D. R. E. Cotton, J. Winter, W. Miller, and L. Dalla Valle, "Is students' energy literacy related to their university's position in a sustainability ranking?," *Environ Educ Res*, vol. 24, no. 11, pp. 1611–1626, Nov. 2018, doi: 10.1080/13504622.2017.1395394.

[31] M. Turner, C. Foreman, and K. Perusich, "Development of an electric energy literacy survey," *International Energy and Sustainability Conference 2014, IESC 2014*, Mar. 2014, doi: 10.1109/IESC.2014.7061839.

[32] M. Prince, M. Vigeant, and K. Nottis, "Development of the Heat and Energy Concept Inventory: Preliminary Results on the Prevalence and Persistence of Engineering Students' Misconceptions," *Journal of Engineering Education*, vol. 101, no. 3, pp. 412–438, Jul. 2012, doi: 10.1002/J.2168-9830.2012.TB00056.X.

[33] D. Wemyss, E. Lobsiger-Kägi, S. Jud, and F. Cellina, "Leveraging realities of saving energy at home: Contributions of co-design to behavioural interventions," *Energy Res Soc Sci*, vol. 104, p. 103258, Oct. 2023, doi: 10.1016/J.ERSS.2023.103258.

[34] A. Satre-Meloy, "Investigating structural and occupant drivers of annual residential electricity consumption using regularization in regression models," *Energy*, vol. 174, pp. 148–168, May 2019, doi: 10.1016/J.ENERGY.2019.01.157.

[35] Z. Ilham, I. Subramaniam, A. Jamaludin, W. Wan-Mohtar, S. Halim-Lim, H. Ohgaki, K. Ishihara, and M. Mansor, "Analysing dimensions and indicators to design energy education framework in Malaysia using the analytic hierarchy process (AHP)," *Energy Reports*, vol. 8, pp. 1013–1024, Nov. 2022, doi: 10.1016/J.EGYR.2022.07.126.

[36] E. Ntona, G. Arabatzis, and G. L. Kyriakopoulos, "Energy saving: Views and attitudes of students in secondary education," *Renewable and Sustainable Energy Reviews*, vol. 46, pp. 1–15, Jun. 2015, doi: 10.1016/J.RSER.2015.02.033.

[37] H. Lucas, S. Pinnington, and L. F. Cabeza, "Education and training gaps in the renewable energy sector," *Solar Energy*, vol. 173, pp. 449–455, Oct. 2018, doi: 10.1016/J.SOLENER.2018.07.061.

[38] C. I. Davidson *et al.*, "Preparing future engineers for challenges of the 21st century: Sustainable engineering," *J Clean Prod*, vol. 18, no. 7, pp. 698–701, May 2010, doi: 10.1016/J.JCLEPRO.2009.12.021.